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William Gilbert and Magnetism in 1600

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IF all the magnetic materials in the world were suddenly, completely and permanently demagnetized, our modern civilization would crumble to pieces: all our practical sources of electric power would go dead; lights would go out, motors would fail and transportation systems stop; telephones and telegraphs would cease to function; in short, we should find ourselves transported back to that golden age of the pre-nineteenth century when people did not have to worry about such complexities, and when magnetism was merely a plaything in the hands of a few curious experimenters. It is a truism that we tend to take for granted blessings long since bestowed. Yet it is often a useful experience to consider how important in our modern life a simple natural phenomenon can become. This serves to whet our interest in the phenomenon and thus, indirectly, in the ofttimes unusual people who have studied it. It is to the examination of the work of one of these people, namely, the Elizabethan physician and philosopher, WILLIAM GILBERT, that the present essay is devoted.

In order to appreciate the significance of the work of any scientist, it is necessary to get vividly in mind several auxiliary details. These include a survey of the previous history of his science with particular reference to what was known and believed about it in his own time. Moreover, to understand the scientific investigator's contribution, one must develop some appreciation of the general atmosphere of his period and the attitude then taken toward scientific research.

Let us, then, first glance briefly at the history of magnetism. Like many other natural phenomena, no one knows who first observed it; its discovery is shrouded in the mists of antiquity. But certainly the two fundamental properties of the loadstone or natural magnet, namely, its ability to attract pieces of iron and its directive tendency when freely suspended, were known to the Chinese and the Greeks by, if not before, 300 B.C. The German naturalist Humboldt, indeed, would have us believe that the Chinese knew of the magnetic compass in the year 1100 B.C. Certain scholars have interpreted passages in the *Odyssey* as indicating that the loadstone was known to Greek sailors at the time of the siege of Troy.

These attributions, it must be confessed, demand considerable imagination on the part of the reader; indeed, the present writer, not professing to be an authority on the history of science, may be permitted a parenthetical note of wonder as to how much of the history of ancient science has validity. Since so much rests on the interpretation by the student, it seems inevitable that many modern preconceptions and prejudices will be read into ancient texts, so that the history of science becomes, like other branches of science, a discipline in which the theory of what things mean is as important as the facts themselves. This must, of course, not be taken as a diatribe against

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investigations into the history of science; it means simply that, in general, we must treat them as we would any other scientific theory.

It seems fair to say that up to the middle of the thirteenth century all that was definitely known about magnetism was represented by the two properties of the loadstone already mentioned. It is true that many authors had paid their respects to the phenomenon with the exaggerative, mystical tendency typical of the period. Thus at various times during the Middle Ages magnets were asserted to be a cure for all sorts of diseases from toothache and headache to gout and dropsy. One author maintained it was of great value in disputes, possibly the basis of the remark of another that it could serve to reconcile husbands to their wives. Precise details of the method of use in this connection are lacking. Among other things, it was also believed that a magnet which had lost its power of attracting iron could have it restored by immersion in the blood of a buck or a goat. On the other hand, some supposed that a magnet rubbed with garlic would lose its magnetic property. To the same class belong the stories told of the famous high rocks in the Indian Ocean which are full of loadstones and draw the nails out of the ships that come near them.

The first serious treatise on magnetism judged by modern standards is generally believed to be that of PETRUS PEREGRINUS, the Picard philosopher, who in 1269 wrote a letter to a soldier friend describing actual experiments which he had performed with loadstones. P. F. MOTTELAY[1] calls this letter the earliest known treatise on experimental science. Though this is a rather strong statement, there is no question that PEREGRINUS' letter was a remarkable document. If it has been fairly translated it indicates that PEREGRINUS was familiar with the *poles* of the loadstone and the fact that unlike poles tend to attract while like poles tend to repel one another. He also relates how a piece of ordinary iron may become a magnet on being rubbed by a loadstone, evidently foreshadowing the production of artificial magnets. PEREGRINUS was the first to suggest the study of the loadstone by making it in the form of a sphere—a terrella, or "little earth," as it came to be called. Whether this should be taken to signify his realization of the earth as a magnet is a moot question. At any rate he made an important advance in the use of the magnet as a compass by giving explicit directions for the construction of two types of such instruments. It also appears that he observed the variation in the compass needle that it does not point to the true geographic north. From the standpoint of a modern physicist, the only blot on the scutcheon of this ingenious man was his suggestion that a perpetual motion machine might be devised with the use of the loadstone. However, his device does not appear materially more implausible than most of those that have been proposed by indomitable inventors of rather recent times. If one can believe the manuscript, PEREGRINUS was a remarkable man; one would like to know more about an individual who, during the thirteenth century, knew so much more than his contemporaries about the nature of magnetism. There is a theory that he owed much of his knowledge to his distinguished contemporary, ROGER BACON, who indeed refers to him in very flattering terms. It seems certain that many of the ideas of WILLIAM GILBERT were suggested by the work of PEREGRINUS.

The period from PEREGRINUS to the middle of the sixteenth century witnessed the widespread development of ocean navigation with the

[1] *Bibliographical history of electricity and magnetism* (London, 1922), p. 46. We are indebted to this work and to the same author's translation of William Gilbert's *De magnete* (Wiley, 1893) for much of the material used in the present paper. Reference should also be made here to the later translation brought out in 1900 for the Gilbert Club in London by the Chiswick Press. Professor S. P. Thompson was the chief editor, and his collaborators in the translation included Latimer Clark, Sir B. W. Richardson, Rev. A. W. Howard, Professor R. A. Sampson, Sir Joseph Larmor, Professor Raphael Meldola, Edward Little, G. T. Dickin and Rev. W. C. Howell. Professor Thompson also prepared in connection with the translation an elaborate set of notes. Only 250 copies of the edition were printed and it is already very scarce. The Gilbert Club was founded in 1889, largely through the enthusiastic interest of Thompson, for the express purpose of commemorating Gilbert's book and preparing a translation of it for the tercentenary celebration in 1900. The translation is a page for page reproduction of the original edition in every respect but the language. Over a period of some ten years, Thompson brought out a number of privately printed articles and pamphlets concerning Gilbert. For a description and discussion of these, the reader is referred to the biography: *Silvanus Phillips Thompson. His life and letters*, by J. S. Thompson and H. G. Thompson (Dutton, 1920).

Although it is now generally agreed that the Gilbert Club translation is the definitive one, further references in the present paper will be to the Mottelay version, as this is generally more accessible.

"William Gilbert, M. D.—Electrician." [From Mottelay's translation of *De magnete*.]

growing use of the magnetic compass and a very gradual increase in the understanding of its vagaries. COLUMBUS, of course, recognized the variation of the compass, or *declination*, as it is now technically known, and, more important still, the change in the declination with longitude. On his initial voyage to the west he passed the agonic line or line of zero declination. It will be recalled that the variation caused some consternation when first observed by his navigators. By the year 1550 it seems clear that the dip or *inclination* of the magnetic needle had been observed, probably first by a German named HARTMANN of Nuremberg, though the discovery is commonly attributed to the English compass manufacturer ROBERT NORMAN, who is the authority for the statement that the dip at London in 1576 was 71°50′.

From the fourteenth and fifteenth centuries little of importance has come down to us about fundamental magnetic phenomena, save the facts about the practical use of the compass just cited. PARACELSUS (1493–1541) collected assiduously all the hoary tales of the wonderful properties of the loadstone and added a few new ones which indicate that he was a better storyteller than experimenter. An Italian named PORTA (1540–1615) took the trouble to examine the old fables and, in some cases, performed experiments to demonstrate their objective falsity. Beyond this he does not appear to have added fundamentally to the knowledge of the subject.

This, in brief, sets the stage for the appearance on the scene of the great systematizer of magnetic philosophy, WILLIAM GILBERT (1540–1603), whose period of activity was the latter half of the sixteenth century and whose great book *De magnete*, published in 1600, was the fruit of seventeen years of labor and research. It will be worth while to consider for a moment the general state of science in Europe during the time when GILBERT was carrying on his investigations. The movement which we now call the Renaissance had been flourishing for more than a century, and science, no less than literature, was feeling the effects of the new enthusiasm for learning. It is true that much of the scientific side of the intellectual rebirth was a rediscovery of, and slavish commentary on, the scientific speculation of the Greeks and of Aristotle in particular. Nevertheless, the age produced a number of individuals who showed a decided tendency to strike out for themselves and to find out how things really behave independently of what others had said about them. Among these were, for example, the versatile genius LEONARDO DA VINCI and the path-breaking astronomer COPERNICUS. While GILBERT was experimenting, a countryman of his who indeed achieved greater material success in politics than in science was urging experimentation as the only real way of adding to human knowledge. On the continent TYCHO BRAHE was engaged in the careful observations of planetary motions which were later to be so useful to KEPLER in establishing the orbits of the bodies of the solar system. Mechanics was on the verge of an entirely new method of approach with the work of GALILEO, marking the birth of what we may justly call the method of modern physics. It was a time when timid souls could satisfy their thirst for learning by drinking deep at the fount of the ancients, while there was a spirit in the air that somehow en-

couraged others to look to nature herself for their knowledge.

Such a one was GILBERT. In the preface to his book he emphasizes that the true philosophers are those "who not only in books but in things themselves look for knowledge," for "in the discovery of secret things and in the investigation of hidden causes, stronger reasons are obtained from sure experiments and demonstrated arguments than from probable conjectures and the opinions of philosophical speculators of the common sort." GILBERT followed the Baconian advice: he not only *talked* about the desirability of performing experiments but he actually carried them out, with the result that he laid a secure foundation for the future study of magnetism and indeed of electricity also.

The known facts of GILBERT's life are relatively few. Born in 1540 in Colchester, County Essex in England, GILBERT, or as the family apparently preferred to spell the name, GILBERD, attended the grammar school of his native town and entered St. John's College, Cambridge, in his eighteenth year. The records show he obtained his bachelor's degree in 1560, the M.A. in 1564 and the M.D. in 1569. In his travels thereafter on the Continent he apparently acquired another doctor's degree in medicine and carried on a medical practice. On his return to England in 1573, he continued as a practicing physician in London and achieved a high place in the profession, becoming in 1600 president of the Royal College of Physicians, which had been founded in 1518 by Henry VIII "to rescue the art of healing from mischievous ignorance" [Hallam]. GILBERT's prestige became so great that Queen Elizabeth appointed him one of her physicians-in-ordinary and settled on him a pension. Precisely when this appointment was made does not appear to be known, but GILBERT kept the position until the death of the Queen on March 24, 1603. He was continued in the same post by JAMES I, but did not long survive, since he died on November 30 of the same year, which was one in which the plague flourished, though it is not known whether this was the cause of his death. GILBERT was buried in Colchester, where a monument to him was erected by his brothers.

Doctor Thomas Fuller[2] describes Gilbert in the following fashion:

> One saith of him that he was *Stoicall*, but not *Cynicall*, which I understand *Reserved*, but not *Morose*, never married, purposely to be more beneficial to his brethren. Such his *Loyalty* to the Queen that, as if unwilling to survive, he dyed in the same year with her, 1603. His *Stature* was *Tall*, *Complexion Chearful*, an Happiness not ordinary in so hard a student and retired a person.

GILBERT's library and scientific apparatus were bequeathed to the College of Physicians but were lost in the great fire of 1666. Only one known portrait has survived to the present day.

It is always a source of fascination to try to imagine what must have been the actual daily life of such a man as GILBERT. Perhaps, if, like BOYLE, he had had close relatives in high places, more information would be available on this point. In GILBERT's day few but the politicians apparently had discovered the importance of leaving an adequate record of their lives and actions for posterity. Nowadays scientists are becoming more obliging in this matter; whether this indicates a decreasing sense of modesty on their part is a question we shall not endeavor to answer. As for the way in which GILBERT thought about things scientific, fortunately we can form some opinion by an examination of his writings and, in particular, the famous *De magnete*.

GILBERT's book, whose complete Latin title is *De Magnete magneticisque corporibus et de magno magnete tellure; Physiologia nova, plurimis et argumentis et experimentis demonstrata*, may well be considered the first extensive treatise on magnetism. It also marks him in the opinion of many authorities as the foremost scientist of Elizabethan England. However, it does not appear that he was actually so regarded in the England of his day, though his book created a considerable stir on the Continent and made a decidedly favorable impression on his contemporary, GALILEO, then engaged in the epoch-making work on the foundations of mechanics. In his famous *Dialogues concerning the two great systems of the world* (first published in 1632), the Italian scientist makes one of his characters speak of GILBERT in the following somewhat exaggerative terms:

> I highly praise, admire and envy this author for having formed such a stupendous conception on a matter which has been treated by many sublime

[2] *History of the worthies of England* (London, 1662).

> intellects, but solved by none: he appears to me also to deserve the highest praise for his many and true observations, putting to shame the lying and vain authors who write not only of what they know, but also of what they hear from the silly crowd, without satisfying themselves by experiment of what is true—perhaps, because they do not wish to shorten their books.

There is, to be sure, one critical note, which might have been expected from GALILEO:

> What I should have desired in Gilbert is that he would have been a little more of a mathematician, and especially well schooled in geometry, the practice of which would have made him less inclined to accept as conclusive proofs, what are only arguments in favour of the deductions he draws from his observations.

In London it might be supposed that BACON, whose philosophic dictates GILBERT was largely following out in practice, would have welcomed the new treatise with enthusiasm. This is scarcely the proper way to describe BACON's attitude. He approved indeed of GILBERT's experimentation, but, apparently feeling that only BACON should be allowed to generalize and speculate, he wrote:

> Gilbert has attempted to raise a general system upon the magnet, endeavoring to build a ship out of materials not sufficient to make the rowing pins of a boat.

Whether BACON's adverse criticism had a serious effect on the success of GILBERT's book is an open question. It certainly is a fact, at any rate, that relatively little attention was paid to it in England until the early nineteenth century. We then encounter the rediscovery of GILBERT and his work with somewhat effusive praise of his early use of the scientific method.[3]

Let us examine the book itself and see what we can make of it. In the first place it is a rather substantial treatise written in somewhat discursive style, so that in the English translation of MOTTELAY it extends to over 350 octavo pages. It is rather profusely illustrated with line drawings to clarify the description of the experiments and arguments of the author. There is a division into six "books," organized more or less coherently with respect to the topics treated. Book I contains a historical review of the previous discoveries in magnetism with a frank exposure of myths and errors. This is followed by a factual account of the chemical and physical nature of the loadstone with a clear statement of its relation to iron ore. The first book ends with the revelation of GILBERT's theory that the earth is a huge magnet. Book II discusses attraction and introduces at the beginning the celebrated comparison between magnetic and electric attraction; the rest of Book II is devoted to a thorough discussion of the attractive properties of magnets. Book III takes up the directive force which the earth exerts on a loadstone or on an artificial magnet made from a loadstone. Book IV discusses the declination of the magnetic compass, and Book V, the dip or inclination. Book VI, the concluding one, treats exclusively of the earth as a spherical magnet and gives the author opportunity to express his adherence to the Copernican view of the rotation of the earth on its axis; there is considerable unsupported speculation in this book, and the connection between the earth's magnetic properties and its rotation, though emphasized as significant, is nowhere clearly explained.

The preceding brief catalog of the contents of *De magnete* cannot, of course, do justice to its essential contributions. If we may believe the preface, the author's main reason for carrying out his investigations and writing his treatise was to put forth and support a new theory of the nature of the earth. This is probably the thing of least interest to the modern student of magnetism, though to the student of the philosophy of the Renaissance it is doubtless very revealing. Much more important for modern physics is the fact that GILBERT did not content himself with mere verbal philosophizing but carried out actual experiments and made an honest attempt to found his theories on these experiments. Hence, physicists today are inevitably attracted mainly to GILBERT's experimental results and the conclusions directly drawn from them. Here we are principally impressed by his observation of things apparently overlooked by his predecessors. Previous philosophers had observed that a magnet possesses polarity and that, while opposite poles attract, like poles repel. It had also been observed that artificial magnets can be made by rubbing iron on a natural magnet.

[3] See, for example, the account by John Robinson in his *System of mechanical philosophy* (London, 1822).

But GILBERT went further and discovered that iron can be magnetized without touching a magnet directly. In other words, he discovered magnetic *induction* through space. Since most magnetization in modern instruments takes place in this way, perhaps this deserves to be ranked as GILBERT's most significant discovery. Thus, when a heated bar of iron is placed along the meridian and allowed to cool in this position, it is found to be magnetized and, indeed, with its north pole pointing to the north. GILBERT realized, and this was probably also his own discovery, that heating a magnet to red heat destroys its magnetism. He also learned, however, that if the demagnetized iron or iron ore is allowed to cool when lying in the proper direction or near a strong magnet it will become remagnetized. The effect of heat on magnetism has been the starting point of much modern research on the subject, and here again GILBERT was a genuine pioneer.

For the clearer description of magnetic experiments, GILBERT invented the concept of the magnetic field. An experiment in which he evidently took great pleasure involved placing very short pieces of iron wire on a terrella, or loadstone made in the shape of a sphere. If the loadstone is sufficiently strong the short wires stick up from the surface at all points save those on the magnetic equator. There they lie tangent to the surface. At the poles the wires stand perpendicular to the surface. At intermediate points they are oblique to the radii drawn to these points. The situation is exemplified in Fig. 1, which occurs in several places in *De magnete*. GILBERT used the orientation of the wires as an indication of the direction of the magnetic force in the region surrounding the loadstone. This region he called the "orbis virtutis," literally the "region of strength," or as we now call it, the *field of force*. This is also referred to as a sphere of influence within which the magnet can act on other pieces of iron. GILBERT probably had little or no conception of force from the dynamic point of view, and hence his use of the term must be regarded as merely qualitatively descriptive. There is no evidence that he connected the decrease of the magnetic influence with distance from the magnet with any geometric property: he evidently had no glimpse of the inverse square law. This is scarcely surprising as the Newtonian epoch was still nearly a century away. On the other hand, we may justly share GALILEO's regret that GILBERT refrained from a quantitative study of the magnetic field. He does, indeed, quote with approval a scheme of PORTA to estimate the strength of a loadstone by means of a balance. This has distinct quantitative possibilities, but GILBERT presumably did not care to follow it up. Mechanics needed the spark supplied by the genius of GALILEO before it was in a state to be applied successfully to magnetic phenomena.

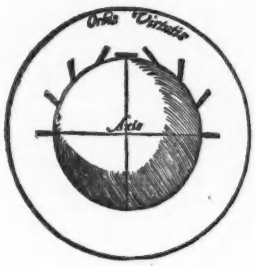

FIG. 1. Gilbert's "orbis virtutis." [Mottelay's translation.]

Some modern commentators have thought that GILBERT had a notion of the concept of mass as distinct from weight.[4] Indeed, MOTTELAY and the Gilbert Club translators of *De magnete* use the word *mass* in connection with the discussion in which the strength of a loadstone is said to be proportional to its size—assuming, of course, that the various pieces under comparison are cut from the same stone. However, a careful reading fails to convince one that Gilbert had any notion of mass in the dynamic sense; his idea hardly went beyond the concept of quantity as measured by size. This is a good illustration of the great difficulty encountered by the modern scientist in interpreting the work of his early predecessors. There is a constant temptation to read into this work our own preconceived ideas and thus to make the author more modern than he could ever have dreamed of being. People who like to exclaim that there is nothing new under the sun do so with the tacit assumption that human beings think precisely the same way from age to age. This has never been demonstrated and probably never can be.

Without doubt, one of the reasons why GILBERT's book impresses us today as a monumental advance in the science of magnetism is that he devised new and much-improved apparatus for his experimental investigations. This is, to be sure, closely connected with the growth during his age of the urge toward experimenta-

[4] Cf. Sir W. Dampier, *History of science*, p. 136.

tion as the ideal procedure in the description of nature. Experiments demand apparatus, and it is clear that the success of scientific research rests on the development of appropriate devices. It is not necessary that these should be particularly elaborate; some of the greatest discoveries in physics have been made with what we should today call very simple apparatus. The point is that it must be *appropriate* for the subject under study. This is where the genius of the successful investigator displays itself. Now GILBERT introduced and used widely a very simple instrument, the "versorium," which is merely a light compass needle mounted on a sharp point so as to rotate freely on a vertical axis. Previous investigators had studied the behavior of magnets by floating them on water by means of wood or cork. But GILBERT's versorium, simple as it was, proved to be a much more flexible instrument and better adapted to a larger field of investigation. With this he was not only able to repeat under better controlled conditions all the old experiments of PEREGRINUS, PORTA and others on the law of polarity, the appearance of new poles when a magnet is broken in two, the destruction of magnetism with heat, etc., but was also in a position to study the new effects of induction which were his own significant contribution.

The versorium played a particularly conspicuous role in what was probably GILBERT's greatest contribution to science, the recognition that the earth is a magnet. It is impossible to read his book without sensing repeatedly the delight which he took in the analogy between the behavior of the little versorium on the surface of the terrella and the behavior of the compass or dipping needle on the surface of the earth. Whereas his predecessors had commonly attributed the directive tendency of the compass needle to some extraterrestrial cause, some "property of the heavens," for example, the action of the pole star, GILBERT saw clearly from the experiments on his spherical loadstones that this was wholly unnecessary: the simple assumption that the earth is a huge magnet is sufficient to account for all the phenomena observed by mariners and others using the magnetic compass. This was a wholesome application of the famous razor of WILLIAM OF OCCAM, the principle of parsimony: "Entia non sunt multiplicandum praeter necessitatem."

As has already been mentioned, GILBERT devoted four of the six books of his treatise to the earth as a magnet. Much attention was necessarily focused on the important properties of declination and inclination. New designs were suggested for the construction of the mariner's compass and dipping needles. GILBERT's design of the former was not a happy one and, though widely used during the eighteenth century, was discarded in the nineteenth. On the other hand his dipping needle is much like that in use today. Since complete knowledge of terrestrial magnetism is not possible except through careful observations at many places on the earth's surface, it is not surprising that GILBERT's views on the subject have undergone considerable revision since his time. He was wrong, for example, in stating that the declination is constant at any one place on the earth. Evidently the previous observations at his disposal were not sufficiently accurate to show the small but definite secular change. It is interesting to note that the effect was actually discovered by HENRY GELLIBRAND of Gresham College, London, in 1633; he pointed out that the declination in London had changed from 11° E in 1580 to 4° E in 1633. The declination there became 0° in 1659 and then changed to west, reaching the maximum value of 24°.5 W in 1823. It has decreased again since that time and the estimate is that it will be zero again in 2139, an interval of some 480 years from the last time. If indeed the phenomenon is truly periodic, a result which we shall have to leave to our descendants to settle, the period would appear to be of the order of 960 years.

The observed variation in declination from place to place was a challenge to anyone's ingenuity, and GILBERT responded nobly. He proposed the interesting theory that declination is due to irregularities in, and specifically elevations on, the earth's surface. Thus he sought the reason for the easterly declination observed at his time along the western coast of Europe in the greater attraction of the high continental land with its mountain ranges than that of the ocean to the west. As an interesting generalization of this theory GILBERT argued for the existence of an open water passage in Northern Europe from

the Atlantic to the Pacific, finding his reason in the large westerly declination prevailing at that time in Nova Zembla, which on his view indicated no continental land extending toward the east in the arctic regions. Hence GILBERT favored a northeast over a northwest passage. His whole argument founders, of course, on the actually existent secular variation of the magnetic properties.

PORTA, and before him PETER PLANCIUS, had conceived the idea that the declination varies in a regular way with the longitude and, hence, that a method is provided for the estimation of longitude independent of astronomical considerations. GILBERT took pleasure in exploding this theory with ample experimental evidence to the contrary. Interestingly enough, however, he fell into a somewhat similar error himself with respect to the magnetic measurement of latitude. His searching investigation into the behavior of the versorium on the magnetic terrella led him to formulate a very precise relation between the dip and the latitude. This, incidentally, is one of the few bits of genuine mathematical theorizing in *De magnete*. Unfortunately, the reasoning is by no means entirely clear and would, one supposes, have scarcely satisfied GALILEO. In any event, it raised considerable enthusiasm in GILBERT and he tried to apply it directly to the earth, feeling undoubtedly that he was thereby revolutionizing the art of sailing and rendering mariners independent of the stars. Unfortunately, the actual magnetic lines of equal dip, or *isoclinic* lines, do not follow at all precisely the parallels of latitude, as any good magnetic map shows. So GILBERT's fine theory had to go the way of PORTA's. However, we ought to point out that, from the standpoint of modern physics, GILBERT was justified in thinking the variation of dip with latitude to be a much more definitely predictable effect than is the variation of declination with longitude. The reason is a simple one: on the *ideally* magnetized terrella there are only two definite poles, or points at which the dip is 90°, and because of the symmetry there can be no declination at all, if one treats the magnetic axis as the geometrical axis of the terrella. On the other hand, there *is* a definite, clear-cut variation of dip with latitude on the terrella. Hence GILBERT should be pardoned for thinking that the actually observed declination-variation on the earth is due to local irregularities and, therefore, of no use in predicting position, whereas the observed dip ought to bear a close relation to the latitude. He should have realized, of course, that the same irregularities might also play havoc with his theoretically computed dip-latitude relation. It may be remarked parenthetically that the magnetic field intensity and variation of inclination with latitude for a uniformly magnetized sphere can be readily worked out. This was probably done by GAUSS in the first instance in 1839. It can then be shown that $\tan \phi = 2 \tan \theta$, where ϕ is the dip and θ is the latitude. This does not agree precisely with GILBERT's variation relation, as Fig. 2 shows,[5] though the difference is rather slight at low latitudes.

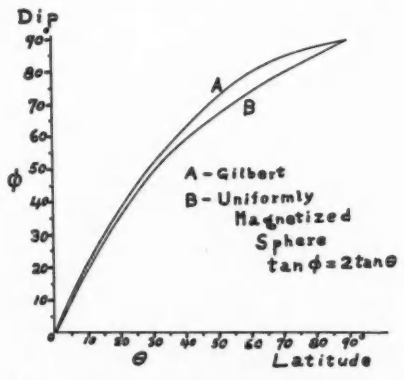

FIG. 2. Comparison of Gilbert's dip-latitude relation with that for a uniformly magnetized sphere.

It may be worth while to follow through the derivation of Gilbert's dip-latitude relation. As might perhaps be expected, it was not expressed analytically but was thrown into geometric form and was not explained very clearly. Gilbert's actual construction[6] is reproduced here in Fig. 3. Since this diagram is somewhat involved due to Gilbert's desire to calculate the dip for every 5° of latitude, a simplified version is presented in Fig. 4. The circle of radius a with center at O represents the cross section of the earth. We shall call this the *fundamental circle*. The equatorial axis is $E'OE$, while the polar axis is POP'. The tangent to the circle is drawn at E, and AE is laid off equal to the radius. With E as center, the arc AO is drawn,

[5] The author wishes to express his appreciation of the assistance of Mr. L. W. Labaw and his colleague, Professor C. W. Miller, in connection with the drawings and photographic reproductions in this paper.

[6] Mottelay's translation, pp. 294, 298.

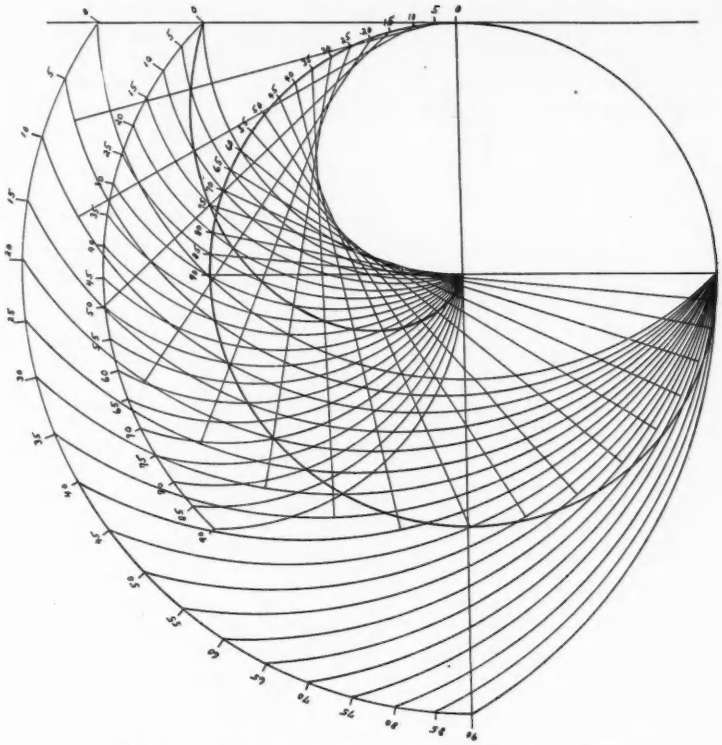

FIG. 3. Gilbert's construction for his dip-latitude relation.

as well as the concentric circle through A. Moreover, on the tangent line EB is laid off equal to EP'. The concentric circle through B and the arc BPP' are drawn. The problem is to construct the angle of dip for the point Q with latitude θ. With Q as center, construct the arc of radius a. Let this intersect the circle through A in the point M. Then, from the construction, QM is tangent to the fundamental circle. With Q as center, further construct the arc of radius QP' and let this intersect the circle through B in the point R. We shall denote the angle at Q between QM and QR as χ. Now draw QL in such a way that $\angle RQL[=\alpha]$ is the $2\theta/\pi$th part of $\angle RQP'$. According to Gilbert's construction the dip is given by the relation[7]

$$\phi=\chi+\alpha. \tag{1}$$

In this relation both χ and α are functions of the latitude and are relatively easily determined. Thus, if we denote $\angle RQO$ by β, so that $\beta+\chi=\frac{1}{2}\pi$, it follows from Fig. 4 with the use of the cosine theorem of trigonometry that

$$\cos\beta=\sin\theta/\sqrt{2}(1+\sin\theta)^{\frac{1}{2}}=\sin\chi.$$

Hence

$$\chi=\arcsin\left[\sin\theta/\sqrt{2}(1+\sin\theta)^{\frac{1}{2}}\right].$$

If we denote $\angle OQP'$ by γ, it follows that $\angle RQP'=\beta+\gamma$

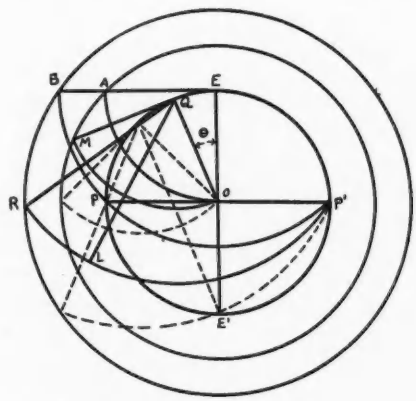

FIG. 4. Simplified version of Fig. 3.

[7] This is by no means immediately clear from the construction given on p. 298 of Mottelay's translation. There Gilbert has drawn a certain spiral curve from A to O. The line QL is then drawn so as to pass through the intersection of this spiral curve with the arc MO. Gilbert, however, makes no statement about how the spiral curve is to be drawn. Only an examination of his construction reveals the equivalence of his method with that presented here.

A ſhort Appendix annexed to the former Treatiſe by *Edward Wright*, at the motion of the right Worſhipfull M. Doctor *Gilbert*.

Becauſe the making and vſing of the foreſaid Inſtrument, for finding the Latitude by the declination of the Magneticall Needle, will bee too troubleſome for the moſt part of Sea-men, being notwithſtanding a thing moſt worthie to be put in daily practiſe, eſpecially by ſuch as vndertake long voyages: it was thought meet by my worſhipfull friend M. Doctor Gilbert, that (according to M. Blundeuiles earneſt requeſt) this Table following ſhould be hereunto adioined; which M. Henry Brigs (profeſſor of Geometrie in Greſham Colledge at London) calculated and made out of the doctrine and tables of Triangles, according to the Geometricall grounds and reaſon of this Inſtrument, appearing in the 7 and 8 Chapter of M. Doctor Gilberts fift booke of the Loadſtone. By help of which Table, the Magneticall declination being giuen, the height of the Pole may moſt eaſily be found, after this manner.

With the Inſtrument of Declination before deſcribed, find out what the Magneticall declination is at the place where you are: Then looke that Magneticall declination in the ſecond Collume of this Table, and in the ſame line immediatly towards the left hand, you ſhall find the height of the Pole in that ſame place, vnleſſe there be ſome variation of the declination, which muſt be found out by particular obſeruation in euery place.

The Table followeth on the next Page.

Firſt Collumn. Height of the Pole. Degrees.	Second Collumn. Magnetick declination. Degr.	Min.	Firſt Collumn. Height of the Pole. Degrees.	Second Collumn. Magnetick declination. Degr.	Min.	Firſt Collumn. Height of the Pole. Degrees.	Second Collumn. Magnetick declination. Degr.	Min.
1	0	11	31	11	27	61	78	09
2	0	20	32	11	41	62	80	04
3	0	27	33	12	13	63	80	38
4	0	31	34	12	4	64	81	21
5	0	34	35	12	13	65	82	03
6	0	34	36	12	22	66	82	43
7	0	32	37	12	22	67	83	22
8	0	28	38	12	33	68	83	58
9	0	22	39	12	37	69	84	32
10	0	14	40	12	36	70	84	7
11	0	4	41	12	40	71	84	38
12	0	52	42	12	40	72	84	57
13	0	38	43	12	38	73	85	21
14	0	22	44	12	35	74	85	41
15	0	4	45	12	30	75	86	2
16	0	45	46	12	24	76	86	18
17	0	26	47	12	17	77	86	28
18	0	0	48	12	9	78	86	8
19	0	36	49	12	0	79	87	16
20	0	9	50	11	48	80	87	44
21	0	41	51	11	36	81	88	1
22	1	11	52	11	23	82	88	17
23	1	39	53	11	8	83	88	33
24	2	6	54	10	52	84	88	47
25	2	30	55	10	35	85	89	1
26	2	54	56	10	17	86	89	14
27	3	15	57	9	57	87	89	27
28	3	34	58	9	37	88	89	39
29	3	54	59	9	15	89	89	50
30	4	11	60	8	53	90	90	0

FIG. 5. Blundevile's explanatory note and table.

and, by the construction, $\alpha=(2\theta/\pi)(\beta+\gamma)$. Now from the triangle QOP', we obtain

$$\cos\gamma=(1+\sin\theta)^{\frac{1}{2}}/\sqrt{2}$$

and from the foregoing expression for $\cos\beta$, there follows

$$\alpha=\frac{2\theta}{\pi}(\beta+\gamma)=\frac{2\theta}{\pi}\left[\arccos\frac{(1+\sin\theta)^{\frac{1}{2}}}{\sqrt{2}}+\arccos\frac{\sin\theta}{\sqrt{2}(1+\sin\theta)^{\frac{1}{2}}}\right].$$

Consequently the analytic relation (1) becomes

$$\phi=\arcsin\left[\frac{\sin\theta}{\sqrt{2}(1+\sin\theta)^{\frac{1}{2}}}\right]+\frac{2\theta}{\pi}\left[\arccos\frac{(1+\sin\theta)^{\frac{1}{2}}}{\sqrt{2}}+\arccos\frac{\sin\theta}{\sqrt{2}(1+\sin\theta)^{\frac{1}{2}}}\right]. \quad (2)$$

GILBERT's curve in Fig. 2 is based on Eq. (2). Although it nowhere appears in *De magnete*, it or an alternative equivalent must have been known to the London mathematician HENRY BRIGGS (the inventor of common logarithms). In 1602 an Englishman named BLUNDEVILE published in London a book called *The theoriques of the seven planets*. As an appendix he added a description of GILBERT's method of finding the latitude by the dip and included a numerical table of the relation between ϕ and θ, said to have been computed by BRIGGS "out of the doctrine and tables of Triangles," though no formula is presented. A reproduction of this table is presented in Fig. 5 along with BLUNDEVILE's explanatory note about it. The values agree very closely with those computed from Eq. (2).

It is of some interest to observe that a close approximation to Eq. (2) is found in the simpler equation

$$\phi=3\arcsin\left[\sin\theta/\sqrt{2}(1+\sin\theta)^{\frac{1}{2}}\right], \quad (3)$$

which is equivalent to taking $\alpha=2\chi$ in Eq. (1). If we refer once more to Fig. 3, we see this means geometrically that QL is drawn so that the *chord RL* is equal to the chord subtended on the fundamental circle by 2θ. The dip constructed in this way differs from that computed from Eq. (2) by not more than 2° for any angle θ between 0° and 90°. The agreement is exact for $\theta=45°$. For values of θ between 0° and 45°, ϕ from Eq. (3) is slightly less than ϕ from Eq. (2), while from 45° to 90°, the difference is in the other direction and is somewhat greater, save, of course, for $\theta=90°$. The disagreement of Eq. (3) with BLUNDEVILE's table indicates rather conclusively, however, that GILBERT employed the construction leading to Eq. (2) rather than the simpler one embodied in Eq. (3).

The problem remains: how did GILBERT arrive at his construction? Any answer to this question must forever remain merely conjectural. Only one thing is definite: since he knew nothing of

the Coulomb law for the interaction of magnetic poles he evidently could not have derived his method from any actual assumed distribution of magnetic material. It is more likely that he made fairly careful observations of the behavior of the small steel needles placed on the terrella (Fig. 1) and tried to find the simplest geometric construction which would give a dip-latitude relation agreeing with the observations. The following statement[8] is of interest in this connection:

> On the equator the magnetic iron stands in horizontal equilibrium, but toward the pole on either side of the equator, at every latitude from the beginning of the first degree even to the 90th, it dips; yet, not in ratio to the number of degrees or the arc of the latitude does the magnetic needle dip so many degrees or over a like arc; but over a very different one, *for this movement is in truth not a dipping movement, but really a revolution movement, and it describes an arc of revolution proportioned to the arc of latitude.*

The words italicized by the present writer give a clue to GILBERT's ideas on the dip. Further investigation shows that he believed very strongly—whether or not from experiment is uncertain—that at latitude 45° the dipping needle should point in a direction which, when extended, intersects the terrella in the equatorial plane. As the dotted lines in Fig. 4 indicate, in this special case $\beta=\gamma=\pi/4$ and $\alpha=\pi/4$. The writer is inclined to the opinion that this case gave GILBERT the hint on which he based his whole construction. The rather good agreement between his $\phi-\theta$ relation and that for a uniformly magnetized sphere, especially in the lower latitudes, will remain one of the minor curiosities of terrestrial magnetism. Of course, it would be perfectly possible to find a hypothetical distribution of magnetic material that will give a dip-latitude relation approximating as closely as one wishes to GILBERT's curve. However, this is a project that scarcely seems worth while at this date, since we could attach no particular historical meaning to it.

GILBERT believed that the earth is a great magnet, and so do we today. But why *is* the earth a magnet? GILBERT's answer was that it is somehow animate and possesses a soul. He could not see the sense of endowing such things as cockroaches and worms with the vital spark only to suppose it lacking in our mother earth. GILBERT left the matter there and did not try to explain the difference between a magnetic soul and a nonmagnetic soul. Perhaps he was wise! Since his time many people have tried to explain why the earth is a magnet, but without conspicuous success, despite the fact that we know decidedly more about magnetism in general and about its relations with electricity in particular than GILBERT did. The final solution of the theory of terrestrial magnetism is still in the future.

The last book of *De magnete* is a curious and fascinating one. In this the author abandons the experimental method which he pursued earlier with such success and launches forth into an almost dithyrambic appeal for the Copernican theory of the rotation of the earth based on its magnetic nature. The reasoning is so utterly at variance with that of the earlier parts of the treatise that one finds it difficult to understand why this part was included at all. Two possible reasons suggest themselves. First, GILBERT may have wished to put himself on record as a convinced believer in the rotation of the earth and may have considered that, since his book was essentially a treatise on the earth, this was an appropriate place for the argument. In the second place, he may have seriously felt that the magnetic properties of the earth really do have an important bearing on its rotation. His reasons for thinking this are by no means impressive, and the whole argument based on terrestrial magnetism is of a decidedly speculative character quite of a piece with the vague theorizings which GILBERT attacked with so much gusto when he found them in the works of other, earlier authors. He was human and subject to the frailties of us all. Moreover, it was probably extremely difficult for him to escape from the speculative tendency of the age, in spite of his zeal for experimentation. We can scarcely blame him for this. It must be admitted in this connection that some of his arguments in favor of the rotation of the earth are plausible enough in themselves but they have nothing to do with magnetism.

Since this article is primarily concerned with GILBERT's contribution to magnetism, nothing has been said about his experiments in electricity, which are fully described in Chapter Two, Book II, of *De magnete*. Here he summarized all the

[8] *De magnete*, Mottelay's translation, p. 292.

facts known up to his time on electrification by contact, and contrasted very clearly magnetic and electric phenomena. The versorium invented for the study of magnetism turned out to be very useful also for experiments on electrically charged bodies. But this is another chapter in the history of physics, and we shall not embark on it here.

It is safe to say that GILBERT's fame rests principally on his magnetic experiments and theory. His work provided a great impetus to physical experimentation along all lines and set a fashion in the precise description of nature which has remained dominant ever since his day. We can scarcely bring this review to a better conclusion than by quoting once more from THOMAS FULLER, whose enthusiasm for GILBERT is quaintly expressed in the statement:

> Mahomet's Tombe at Mecha is said strangely to hang up, attracted by some invisible *Loadstone*, but the memory of the Doctor will never fall to the ground, which his incomparable Book *De Magnete* will *support* to Eternity.

College Courses in Physical Meteorology

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THE number of courses in meteorology offered in the colleges of the United States has more than doubled in the past decade. The greater part of the expansion has occurred in teacher-training and technical institutions. This increased interest in meteorology can be attributed, in part at least, to the growth of aviation and its demand for pilots with a better knowledge of the atmosphere.

The types of courses offered in colleges fall quite generally into two classes: one a purely descriptive course, and the other a course dealing with the physical aspects of the atmosphere. The first type, usually taught in the geology or geography departments of the colleges, treats in a qualitative or descriptive way the actions of the atmosphere that constitute weather, and climatology, the generalized or normal conditions of the atmosphere of the earth. The second type, usually taught in the departments of physics, has for its aim a fuller understanding of the physical laws and principles under which the phenomena of the atmosphere exist and operate. This type of course has quite properly been called "physics of the air" and as a physical science should find its highest development and effectiveness in the departments of physics.

Few courses offered in college provide such an abundance of opportunities for the application of physical principles as does a course in physical meteorology; there is scarcely a subdivision of physics that is not invoked to explain some phenomenon of the atmosphere. Mechanics must be called upon to explain why a wind never blows very far in a straight line, and why a wind tends to blow at right angles to the pressure gradient causing it when the forces on it are in equilibrium. Once the forces and their relations are understood, it is easy to see why a hurricane is so stable that it will continue its circular motion for days and even weeks, and why it whirls counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere.

In atmospheric electricity the phenomena vary from minute and seemingly insignificant evidences of atmospheric ionization and conduction to the formation and action of the awe-inspiring thunderstorm with its spectacular and brilliant lightning discharges. Among the most beautiful spectacles of all nature are some of the optical phenomena that occur in the atmosphere. The study of such things as the twinkling of the stars, the formation of halos, mirages and rainbows affords an endless amount of pleasure to the student of physics. The development of the

theory of the rainbow has been a delightfully interesting problem for some two thousand years.

For the student of heat and thermodynamics the situations and applications in meteorology are almost endless; the whole pageant of the weather is energized and actuated by the heat that comes from the sun as insolation.

For a thorough course in physical meteorology the student should have had some preparation. To understand the principles, he should have had as a minimum a good course in general physics; for the development of the equations involved, he should be familiar with the integral calculus. It may not be necessary to derive a formula before its usefulness is understood, but it does add something to the appreciation of the formula and the relations it portrays if the student follows through to the end the arguments establishing its validity. However, a good course in physical meteorology can be given without the aforementioned prerequisites if the physical principles involved are explained by the instructor as they are encountered, and the more difficult derivations are omitted; but the equations used should be discussed and the relations presented should be fully explained. Such a course would require more time, and the instructor would have to teach physical principles also; but he would have an excellent medium for the illustration of the principles, and the course would be much more than informative. Few college courses afford a better opportunity for scientific observation and logical thinking.

The success of any college course depends more upon the instructor than upon any other single factor. This is especially true in the case of a course in physical meteorology, but unfortunately most physicists do not know enough about meteorology to teach it successfully, or they lack the interest and enthusiasm to make a success of the course. The instructor should be both a physicist and a lover of the outdoors; he should have a genuine interest in the weather and the phenomena of the atmosphere in all its varied phases, and should be able to convey his enthusiasm, in some measure at least, to his students. If he has had no previous interest in the subject, it is difficult for even a good physicist to become acquainted and familiar in a short while with any large part of the atmospheric phenomena that are continually occurring about him. On the other hand, if the instructor has always had a lively interest in the weather and the behavior of the atmosphere, it should not be at all difficult for him to familiarize himself with the subject matter of the course and draw upon his experience and observations for applications and illustrations of the principles presented.

A knowledge of some of the sciences other than physics and mathematics will be found useful to the instructor who is planning to teach physical meteorology. An acquaintance with astronomy and geology will often be found helpful, while a familiarity with geography and especially physical geography will be found almost indispensable.

Several types or classes of students are usually interested to some degree in meteorology. Students of agriculture find it desirable, as the farmer is very much dependent upon the vacillations of the weather, and students of civil engineering find it quite helpful in their studies of hydrology and hydrography. Students of aeronautics are especially interested in meteorology, as weather conditions are very important in aviation. The safety of pilots and passengers and the maintenance of flying schedules depend on the weather conditions and the ability of those in charge to anticipate changes in the weather.

It should not be at all difficult to interest students of physics in a course in physical meteorology, especially those who are also interested in the outdoors. In the phenomena of the atmosphere they find so many illustrations of the principles in physics; there they find nature demonstrating in a vivid and forceful way the laws of physics which they have studied in the classroom. In the study of meteorology they find the physical laws and principles tested in a manner that demonstrates clearly their accuracy and limitations.

The serious and ambitious student is looking forward to the time when he can obtain a position and begin his lifework. To him the business of finding for himself a congenial and profitable vocation or profession is a serious matter and he should have the opportunity to investigate as many fields of endeavor as possible. The field of meteorology offers excellent opportunities to

scientifically minded young men who like nature and the outdoors. The United States Weather Bureau and the airways of the nation are employing thousands of young men in their meteorological service; hundreds of them are entering the service each year. It is interesting work; even the routine work of the observer is far from dull, especially to the young man who is trained for it. No better preparation could be obtained for such a position than a thorough training in physical meteorology. Even a beginning course in the subject would help a student toward that goal; at least it would be a start and would help him to decide either for or against the field as a lifework. If he decided against meteorology as a lifework, the efforts spent on the course would not be wasted, for the knowledge gained would enable him to understand the weather better and would be a source of continual satisfaction to him; in this respect the course would certainly have a cultural value. If he decided to continue his training in meteorology, he could pursue more advanced courses in the subject in his own college or in one of the several colleges that offer excellent training in the subject.

College administrations as a rule do not welcome elaborate schemes for the establishment of courses in new subjects, especially when they involve the appointment of new instructors and the purchase of expensive laboratory equipment. Such an expansion is hazardous unless there is a very definite and specific demand for the course, accompanied perhaps by a substantial endowment for it. However, little difficulty is encountered in introducing a course in physical meteorology in the department of physics of most colleges. Usually there is someone in the department who is qualified to teach the course. If it is made optional or elective, it soon becomes popular when taught by an enthusiastic instructor, and there is usually no dearth of students. A demand for more advanced instruction, as well as for laboratory work, usually appears. When this stage of the development is reached, after two or three years, the attitude of the administration is almost certain to be very sympathetic.

The amount of new apparatus needed to begin a course in physical meteorology in the department of physics is usually very small. Most departments have several barometers, both mercurial and aneroid, thermometers of all kinds, dew-point apparatus, psychrometers, barographs, thermographs, and many other pieces of apparatus that could be used to demonstrate the principles and actions of the atmosphere. An ingenious instructor can improvise many excellent pieces of apparatus, such as an absorption hygrometer, from the usual equipment found around a physics laboratory. After the course becomes established, good pieces of apparatus can be added from time to time as the resources of the department will permit.

The nucleus of a reference library on the subject of meteorology can usually be found in the college or department library. In developing this nucleus the bibliographies to be found in textbooks on meteorology would be of considerable assistance. A decade or two ago most of the books on meteorology were largely descriptive and discussed the theories in a qualitative way; they gave much of their space to the discussion of climatology. In recent years a good many books have been published that deal with the physical aspects of the subject. The teacher who is planning a college course in meteorology should have no trouble in finding excellent reference books as well as a suitable textbook for the course.

The subject of meteorology deserves a place in the department of physics; in fact, that is where it rightfully belongs since it is so much a physical subject. Courses might be developed in some colleges to such an extent that a separate department for it would be formed, as has been the case in several of the subdivisions of physics in the past. For example, some 60 or 75 years ago electricity was almost wholly restricted to the field of physics. With the development of electrical engineering it expanded until separate departments were provided for it. Nevertheless, the subject of electricity is still an important part of the course in general physics and, in most departments, advance courses are given in it. The departments of physics of our colleges and universities should develop a lively interest in this most excellent physical subject and should not allow meteorology to pass to other departments through neglect.

The Physicist in Industry

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THERE is a conventional pattern for a discussion of such a subject as "the physicist in industry." This pattern suggests selecting some industrial physicist whose experiences have been typical of the entire group, tracing his progress from the time he was born, preferably on a farm amid underprivileged surroundings, watching him prepare for the university under severe hardships, and finally revealing him in all his glory at the peak of his career when he has become a powerful and indispensable figure of our time. I do not propose to follow that pattern here because, to my knowledge, there does not exist a single industrial physicist, under a strict interpretation of the terms.

To forestall misunderstanding, let me say that there are men in industry who once were physicists, and there are physicists in industrial plants where there might otherwise have been industry. The first proposition scarcely needs elaboration. It is common knowledge that when a physicist embarks upon an industrial career, the features which identify him as a scientist ordinarily begin at once to atrophy because of disuse. For the same reason, he begins to be called an engineer, or perhaps merely an executive. The second proposition relates to physicists who preserve their identities after entering an industrial plant. You will note that I was careful to say that they enter the plant, because they rarely are considered a part of the industrial organization. They are confined in research laboratories where their activities are viewed by the other employees with a mixture of awe and suspicion. So loose is the usual connection between the plant and its research laboratory that the latter never seems to know whether the plant is working at full capacity or is closed down altogether.

So much has been said about the industrial physicist during the last few years that many have been deceived into thinking that this species has already evolved. Actually, the evolution of the industrial physicist awaits the establishment by the universities of a more favorable environment for his development. Until comparatively recent times, the training of a physicist in the university has been based upon the assumption that he would follow the same career as his teacher. In other words, the universities have been cultivating what the farmer would call a seed crop. Much care has been expended in the nurturing of this crop, because the young physicist must be able, independently, to make discoveries beyond the frontiers of existing physical knowledge. Since these frontiers lie at an ever increasing distance, the tendency toward greater concentration on physics is understandable, even when it means that other valuable subjects must be sacrificed.

The advent of industrial research laboratories provided a new type of career for the physicist but did not alter the basic requirements for the Ph.D. in physics. These laboratories have much of the atmosphere of the university, and they often like to pretend that their activities lie exclusively in the domain of pure science. It often happens that their facilities for pure research are somewhat better than those of the university, a circumstance that is supposed to compensate in some measure for the necessity of punching a time clock. A research worker often has almost the same freedom to publish his results that he would enjoy in a university, a privilege that makes the research laboratory less expensive to operate, because investigators are always willing to substitute fame for fortune.

Partly because of the demands of industrial research laboratories, the universities have enormously expanded their departments of physics during the last two decades. On cursory examination, this would seem to be a good thing for physicists, and we like to believe that it is a good thing for the rest of the world. However, there are some who feel very strongly that industrial research laboratories cannot continue to absorb Ph.D.'s at the rate which has prevailed during recent years. It should be remembered that the industrial research laboratory is a phenomenon of comparatively recent origin. The day may not

be far distant when men will be needed primarily for replacement and not to satisfy the acute demands of a rapidly growing organization. Moreover, only large companies can afford research laboratories of the type that can utilize the abilities of our present Ph.D.'s, and, with the temper of the American people what it is today, the number of large companies seems more likely to decrease than to increase.

Despite the fact that an industrial research laboratory has almost invariably shown a profit to the company, it is sometimes questioned whether it can continue indefinitely to do so. To some extent research laboratories have been skimming cream, or it might be better to say that they have been milling their most valuable ore. Personally, I do not subscribe to this theory, but I have some misgivings of a different sort with respect to a career in an industrial research laboratory. To be sure, those who embarked upon such a career in the early days have done remarkably well. In most instances they are now directors or assistant directors of research, positions of considerable responsibility. For obvious reasons, a young physicist starting today cannot, on the average, expect to duplicate that performance. Unless he has unusual talents for leadership, he may be doomed to carry on research for the rest of his life. A young man fresh from the university does not ordinarily regard this prospect as unpleasant; he is still imbued with a passion for science for science's sake which oozed from the very pores of his teachers at the university. His enthusiasm prevents him from picturing himself at a time when his hair has begun to turn gray and his scientific productivity may have begun to wane. Industrial research laboratories are still so young that they have not often had to meet the problem of the employee who can no longer pull his share of the load. Incidentally, this problem does not arise in a university where experience as a teacher generally offsets the diminishing ability as an investigator.

A young man about to join the staff of an industrial research laboratory might well experience some doubts concerning his future for another reason. He can honestly admit to himself that he is better prepared for his career than is the product of the university in any other field of endeavor. For example, a young man emerging from a graduate school of business administration is presumably trained for a vice-presidency of some large corporation, but he must accumulate much experience before he succeeds to that title. So it is also with the young lawyer, the young physician or the young surgeon, who must serve a virtual apprenticeship for several years before even beginning his professional career. On the other hand, a man with a Ph.D. in physics can enter an industrial research laboratory and immediately undertake a research project. He knows all the ordinary tricks of the trade; how to blow glass, wire an amplifier, replace a galvanometer suspension, etc. In fact, he knows his trade so well that he usually receives a larger salary at the start than do other professional men. For the same reason, his advancement in salary must inevitably be slow. He must expect that the universities will continue to turn out men who will be equally well trained; and, so long as these men are in abundance, they establish the prevailing monetary value of an investigator's services. The true investigator is, of course, oblivious to salary considerations, but it often happens that his wife and children are not true investigators.

Some industrial establishments solve these problems by making the laboratory a sort of training school for other positions in the organization. A young man entering such a laboratory will usually be attached to a group that is endeavoring to develop a new product or a new process. When the development is completed and the product is ready for commercial exploitation, new positions in the organization are created because the product must now be manufactured, advertised, merchandized and serviced. These new positions are usually filled by the young men who have had intimate experience with the new product in the laboratory. In this way they become superintendents or assistant superintendents of new departments. More times than not, the new departments become increasingly important to the company, and the chances become correspondingly good that the young superintendents will not be overlooked when changes are made among the major executives of the company.

I like to think that such *development* labora-

tories enable the young physicist to pursue an ideal career. They provide opportunities for the use of his technical training while he is young; and, as he grows older and more experienced in dealing with people, they provide opportunities where such experience can be used to good advantage. The number of such positions is virtually without limit because, although few concerns can afford to carry on fundamental research, no concern today can afford to be without a development laboratory. Such laboratories pay for themselves many times over, even disregarding their value to the company as a training ground for young executives.

There are probably many reasons why young physicists do not more frequently accept employment in such laboratories. Some, after pursuing science for several years on fellowships at endowed educational institutions, would feel insulted if offered a position in a laboratory whose primary purpose is to increase the dividend paid to the stockholders of the company. Others, believing that industry generally pays a man in strict accordance with his worth, feel that they could not afford to live on such a salary. In the vast majority of cases, the controlling reason for the paucity of physicists in development laboratories finds its basis in the fact that, when a vacancy occurs, the company interviews the available physicists and then hires an engineer.

The young physicist who would embark on this type of industrial career undoubtedly is handicapped by the attitude of his teachers in the university. Their standards are so high that a man must have received the doctor's degree before they recognize him as a physicist. Indeed, if he can spend a year or two on a post-doctorate fellowship, so much the better. The graduate of a course in engineering, on the other hand, is regarded as an engineer on the day he receives a bachelor's degree. Furthermore, his course of study is not planned primarily to be preparation for graduate work, but rather to equip him for a useful career at the end of four years of training.

It might be argued that teachers of physics are looking more to the future than are the teachers of engineering. Time was when the college man in industry was an exception; whereas today men entering industry without a bachelor's degree find themselves handicapped. By extrapolation, it might be concluded that postgraduate studies will sometime be an industrial requirement. There are statistics that shed light on this point. I have in mind especially an analysis, made a few years ago by a large electrical manufacturer, of every case in which a technically trained man had left the employ of the company under circumstances where the company knew about his departure before the man did himself. This analysis showed that only 16 percent of this group were dismissed because of inadequate technical ability. The remaining 84 percent were dropped because they did not accept responsibility, would not cooperate with others, were completely lacking in ambition or suffered from other defects of personality. Since those who were dropped for lack of technical ability constituted only 16 percent of the total number dropped and an almost negligible proportion of the total number employed, there is no positive indication that industry is in serious need of men with training beyond what they receive in the average four-year course. The one striking inference to be drawn from these statistics is that, so far as industry is concerned, men with inadequate personalities are not disguised by clothing them with technical training.

Naturally, it distresses me considerably that development laboratories should consider engineers with four years of training more useful than physicists, even physicists with advanced degrees. To be sure, the engineer may know somewhat more of current practices at the start, but this advantage is only temporary. It is more than offset by the fundamental knowledge of the physicist, which should enable him to cope more successfully with the changes in industrial practices that are bound to occur during his lifetime. This situation is truly ironical, because the two years of college physics required of the engineer are, as any physicist will tell you, the most valuable courses in the engineering curriculum. Perhaps, instead of being distressed at the reception which industry accords physicists, we should take pride that we can do so much for students of engineering in so short a space of time. The situation reminds me of the eminent statistician who issued weekly advice to investors

in the stock market. He evidently had the high ideals of the physicist because he resisted the temptation to turn his knowledge to profit by speculating with his own funds. It so happens that this statistician had a Japanese servant who, while waiting on table, was frequently able to overhear parts of the conversation. Acting on the bits of information received in this way, he invested his meager savings in the stock market so successfully that he was able to retire —a wealthy man.

If there is ever to be any considerable number of physicists in industry, it can come about, in my opinion, only if the universities are willing to plan their undergraduate curriculums in such a way as to attract some of the students who otherwise would study engineering. I have no doubt that an industrial demand for physicists could easily be stimulated, and the reaction of industry is notoriously autocatalytic in the sense that the success of one physicist would create a demand for many others. Under such conditions, the average course in undergraduate physics at a university or technical school would be increased to several times its present size and would come to be regarded as the major consideration of the department.

One should be slow to suggest that this change would in anywise hamper the work of the graduate school. On the contrary, a larger group of undergraduates would enable a more intelligent selection to be made of those who possess the concentration of talent that makes advanced studies a profitable venture. The fact that the undergraduate curriculum was not planned primarily to be preparation for graduate study should work no great hardship on this group, because the real pioneers in the field of physics have always been so independent in mind and spirit that they would secure an education under almost any circumstances, apart from the actual destruction of all libraries and laboratories. Needless to say, a larger number of undergraduate students would necessitate a larger number of teachers and this would automatically operate as a stimulant to the graduate school. It might even happen that those who enter development laboratories after four years of training in physics and eventually become major executives would be more likely to engage the services of Ph.D.'s than are the lawyers and bankers who customarily manage industry today.

This program would do much to suppress the present tendency toward overspecialization, which is often cited as the characteristic that makes physicists unsuited for most industrial positions. Time was when physicists had broader interests and called themselves natural philosophers, but the intervening years have witnessed a growing tendency toward specialization which has extended even into the very nucleus of the atom. I had in mind that I might illustrate the consequences of overspecialization by reciting some of the tales that are preserved in the folklore of industry. These tales make it quite clear that industrial plants have occasionally been invaded by physicists who relied entirely on their impregnable armor of specialization. In every instance these physicists have gone down to legendary defeat under circumstances which their successful opponents regarded as highly amusing. On second thought, I realized that these fables might lose much of their force when related by one specialist to readers who are likely to be specialists in the same field. Hence, I am forced to illustrate what industry thinks of the overspecialization of the physicist by introducing to you a specialist in a very different walk of life.

Recently, while undertaking to visit the home of a colleague who lives in Watertown, I lost my way in the darkness and was some two blocks within the limits of the adjoining town of Belmont when I came upon a real estate office. Although I realized that I could not be far from my destination, I decided to make inquiries of the agent in order that I might have the benefit of his specialized knowledge of the locality. When I mentioned the name of the street that I was seeking, the agent dropped his work, looked over his spectacles, and said in a positive tone of voice, "There is no street by that name in the town of Belmont." I naturally apologized for the inadequacy of my question and explained that the street which I sought was located in Watertown, not far from the Belmont town-line. At this, the agent again looked over his spectacles and said with equal firmness, "I know nothing whatever concerning the streets in Watertown."

Teaching Physics to Women

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ACCORDING to data published three years ago,[1] only one out of six of the women studying an elementary science in 36 women's colleges was studying physics. Numerically the situation is at best the same today. Those who have anything to do with registration of freshman and sophomore women students cannot fail to sense the prejudice toward physics and everything else mathematical. The majority of the women who elect the elementary course admit that they are taking it because it is required of premedical students and laboratory technicians.

Whether or not women should be made to see the cultural value of the physical sciences is not the point of the present discussion, but most teachers will agree with Professor Daffin[2] that "physics should be made so attractive to women or any other students, as to cause them to recognize the same enjoyment from it as from any other subject taught in the schools or colleges." In the endeavor, therefore, to make this semi-missionary work of teaching physics to women who elect it because it is required a little more effective—hence, a little more enjoyable—we have made two changes in the presentation of general physics this year. May I remark, however, that though physics is offered only as a minor in the college, the course in general physics is in no sense an adapted or diluted course.

The first change was in the order of presenting the subject matter. A study of tables issued by the Cooperative Test Service had brought an interesting fact to light (Table I). In practically all percentiles, women had scored as high as the men on the test in "Sound." Later investigations may show that the "Sound" test was at fault or that the women received more instruction in sound than did the men; but in the meantime we reasoned that the subject matter of sound falls more within the realm of a woman's experience than does, for example, that of mechanics. To start with the study of sound, therefore, would presumably be both good psychology and better physics. Since mechanics demands more mathematics—again we reasoned—let that come during the second quarter; by that time the student has had a chance to become better adjusted to study and to get some of the rust off the high school, or even college, mathematics.

TABLE I. *Percentile ratings selected from "Tables for the Interpretation of Scores on the Cooperative Physics Tests for College Students."*

PERCENTILE	100			75			50			25		
	Men	Women	Engineers	M	W	E	M	W	E	M	W	E
Mechanics (50)	49	44	49	25	20	26	18	14	20	13	9	15
Sound (16)	16	16	16	10	10	10	8	7	8	5	6	6

Big brother and the boy next door are probably to blame for most of the inferiority complexes, dreads and fears that befall the woman who announces to the family that she has to study physics. It is the teacher's job to convert Miss Premedic—to provide a shock absorber, so to speak. Studying wave motion in sound and light is a much easier way to break down the prejudice than was the former approach with units of measure and vector notation. Falling stones and rifle bullets are not good shock absorbers. The students were rather respectful toward mechanics after they had seen it as the basis for wave motion. They looked up to it instead of askance at it.

The second change—judged by results, also an improvement—was in the supervision of the laboratory period. Since we use the plan of having several experiments going on at the same time and rotating the students in pairs on successive weeks, it is impossible to assemble the entire group and give directions to fill the gap between laboratory text and apparatus. Until that gap is closed, valuable time is lost for a great many students, and the instructor is needed everywhere at once. I have heard of one college where several instructors report for each labora-

[1] Daffin, Am. J. Phys. (Am. Phys. T.) **5**, 82–85 (1937).
[2] Reference 1, p. 84.

tory section and remain until the opening rush is over.

Knowing what teaching a subject does to one's knowledge of it, we thought it good training to let each student have the experience of answering another student's questions. We decided to devote ten or fifteen minutes at the beginning of each period to an exchange partner-instructor session. Once a group of experiments is started, there are always two students in the section who have performed one of the experiments the previous week. By rotating the instructor assignment from one member of a pair to the other, the teacher enables each student to have a turn at being instructor every other week.

With her work spread out over the period, the instructor has a chance to circulate from group to group more efficiently. She has an opportunity to ask a few questions, too. As far as the faculty instructor is concerned, our plan differs decidedly from the one in which "the instructors all reported that they 'had nothing to do' with only sixteen students in a section."[3] In order to watch the student reaction, we delayed introducing the laboratory change until the sixth week of the semester. The students like the change because, as one of them said, "things can't be cloudy in your own mind if you have to tell it all to someone else." We believe certainly that "all the pitfalls should not be anticipated. The experiment should not be easy but should be a real challenge."[4] With elementary work, however, the experiment can still be a challenge even after some of the difficulties have been anticipated.

We feel that the changes we have tried hold possibilities for bringing physics into better favor with women students; for if, as we suspect, prejudice is responsible for the prevailing attitude, the strongest curative influence in a college will be a group of successful, interested students.

[3] Weniger, Am. J. Phys. (Am. Phys. T.) **5**, 63–65 (1937), see p. 63.
[4] Eaton, Am. J. Phys. (Am. Phys. T.) **5**, 47 (1937).

Some Applications of Physics in Pharmacy

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IT is not the intention here to discuss general and cultural reasons that justify the inclusion of some kind of a course in physics in the curriculum of a school of pharmacy. The main purpose is to mention some specific phases of physics that are actually applied in professional and commercial pharmacy.

The druggist is constantly converting from one system of units to another. To appreciate the frequency of this activity, one needs to realize only that official pharmaceutical books utilize the metric system, physicians usually prescribe in the apothecary system and drugs are bought from the manufacturer in the avoirdupois system. While the physics course is not burdened with the whole problem of teaching weights and measures (much of this is done in courses in pharmacy), nevertheless, it is generally conceded that the physics course serves to emphasize the practicality of the metric system, and gives the students valuable and extensive practice in solving problems involving conversions of units.

This ability to manipulate units often enables the pharmacist to perform for physicians and patients the important service of evaluating and comparing similar products of various manufacturers. The field of vitamin preparations is an excellent example. Numerous vitamin B_1 preparations are on the market, the vitamin contents of which may be expressed in Sherman-Case units, or in International units, or in milligrams or micrograms of thiamin chloride. The pharmacist should be able to express these preparations all in terms of the same unit, and advise the

physician of the results. This often enables the patient to secure much more medication for his money.

The pharmacist has definite need for a working knowledge of specific gravity. In the first place, specific gravities of all liquid substances and of many solids are given in the *United States Pharmacopoeia* (*U.S.P.*) as criterions for identity and state of purity; naturally, this involves various methods suitable for determining specific gravities of different types of substances. Second, specific gravity is important in the prescription laboratory since physicians often prescribe medicaments in terms of percentage solutions; where percentage solutions by weight are intended, the pharmacist must be able to work with the specific gravities of liquid ingredients and solvents. Finally, rough calculations involving specific gravities are often necessary in the determination of selling prices, since many liquids are bought by weight but dispensed by volume.

Occasionally a little physics will serve as a handy tool in the art of compounding. For example, consider the prescription,

Pepsin ʒ ss
Potassium Bromide 3 VI
Tr. Belladonna fʒ ss
Aq. Menthae Piperitae q. s. ad fʒ IV.

The writer has found it expedient to add the pepsin and the potassium bromide to part of the peppermint water, then shake vigorously for a minute or so until solution is effected. This produces considerable foam which requires a long time to subside. If, however, the tincture of belladonna (which contains 70 percent alcohol and therefore has a small surface tension) is added slowly to the foamy liquid, the foam immediately disappears, after which the prescription may be brought up to volume with peppermint water. In many similar cases, where a liquid of small surface tension is not included in the prescription, a few drops of alcohol dropped judiciously at separate places on the foamy surface will usually suffice to dissipate the foam. As part of the art of compounding, such unobjectionable additions constitute part of the prerogative of the compounder.

Under each official substance the *U.S.P.* describes a precise chemical method for purposes of assay. However, for quick identification and as reliable criterions of purity, the pharmacist often relies upon specific physical properties. Thus, the *U.S.P.* lists, for nearly pure chemicals, such properties as melting points, congealing points, specific gravities and solubilities in various solvents. Laboratory practice in the technics of determining these physical properties is usually relegated to courses in chemistry and pharmacy.

Various other specific physical properties are occasionally utilized for purposes of identification and determination of purity. These physical methods are especially valuable in the case of naturally occurring mixtures, such as volatile oils, the composition of which is often so complex as to make chemical methods of analysis most difficult, and in the case of complex organic medicaments which are either expensive or none too stable. Thus the *U.S.P. X* listed refractive index ranges for 23 official substances: for example, oil of clove for medicinal purposes must possess a refractive index of from 1.5300 to 1.5350. Since pharmaceutical products present a wide range of refractive indices, the Abbe and Zeiss immersion refractometers are commonly employed.

The importance of optical activity is evident from the fact that the *U.S.P. X* partially defined 42 official substances in terms of their capability of rotating the plane of vibration of polarized light. For example, hyoscine hydrobromide (a hypnotic) is described as providing a specific rotation of not less than $-22°$ and not more than $-22.75°$, using sodium light under carefully stipulated conditions.

Fluorescence has its applications. Many substances, notably certain alkaloids, must fluoresce properly under certain prescribed treatment. Properly used, fluorescence serves to detect petroleum products in fats and oils, to measure deterioration in complex organic medicaments and often to trace chemical changes during process of manufacture.

Colorimetric methods of analysis have been employed for some time, and, as medicaments gradually increase in chemical complexity, should become still more popular. The *U.S.P.* provides colorimetric standards for cod-liver oil, also for use in carbonization tests with sulfuric acid on a number of organic compounds. The use of such standards also permits exact duplication of the

color in intentionally colored preparations. Even turbidimetric methods of analysis have been employed, and the more precise pieces of apparatus for them involve direct applications of photoelectric cells. Gasometric methods of analysis are frequently employed; for example, the *U.S.P. X* method of assaying sweet spirit of niter utilized the liberation of nitric oxide, which occurs when the spirit is treated with potassium iodide and sulfuric acid. Such methods, in addition to demanding a knowledge of the technic of gas manipulation, utilize calculations involving the gas laws.

Various electrolytic phenomena are of importance to the student of pharmacy. He is expected to know the source and general method of manufacture of the materials he uses; and many important medicaments are made electrolytically, for example, caustic soda, caustic potash, chlorine, potassium chlorate, sodium hypochlorite solutions and chloroform. The pharmacopoeia also describes methods for the electrolytic determination of copper, mercury, silver and zinc compounds; in the *U.S.P. X*, specific directions were given for the electroanalysis of 19 individual substances. Again, students must have a fair grasp of hydrogen ion concentration and its expression in terms of *p*H. For reasons of stability and therapeutic activity, some preparations must be adjusted to *p*H's within certain stipulated ranges. It is customary to familiarize the student with both the colorimetric and potentiometric methods.

It is not implied that the foregoing applications of electrolysis are to be presented in the physics course. The applications are actually encountered later on in courses in pharmacy and chemistry. From his physics it is expected the student will recall only the fundamentals—how an electrolyte functions to complete an electric circuit; how electrons are involved in chemical changes; the operation of a potentiometer; how a cell may be set up so that its electromotive force will be a function of the hydrogen ion concentration of the solution surrounding its electrodes; etc.

Petrolatum Liquidum (mineral oil) in both its heavy and its light forms is described as meeting certain viscosity specifications. Humidity measurement and humidity control are also of considerable importance in pharmaceutical manufacturing, since many substances are hygroscopic, while others, such as effervescent salts, deteriorate in the presence of moisture. The packaging of such materials so that they reach the consumer in proper condition is a continual problem. Decomposition on exposure to light causes difficulties too, hence a knowledge of light filters can be utilized to design containers that limit the transmission of the damaging parts of the spectrum.

Simple experiments in spectroscopy are deemed desirable, since the student hears much about emission spectra in his courses in inorganic chemistry, and many references to absorption spectra are encountered in biochemistry, pharmacology and physiology. Emission spectra for identification purposes and for the detection of small amounts of metallic impurities have long been used in pharmacy. With the increasing complexity of organic medicaments, absorption spectra methods probably will become more numerous. They have already been strongly recommended by various workers for the convenient and rapid evaluation of vitamin preparations. For example, the potency of vitamin A preparations is easily determined spectrophotometrically by measuring the intensity of absorption of light of wave-length 3280A; the method is rapid, agrees well with methods based on animal experimentation, and is applicable with acceptable accuracy both to concentrates containing high percentages of vitamin A and to natural products containing a small fraction of 1 percent of vitamin A. Absorption spectra methods for some other vitamins are also available and show promise of great usefulness.

Up to this point, the professional side of pharmacy has been considered. Concerning the commercial side, only a few of many possible applications will be mentioned.

If one were seeking a thermos bottle, but knew nothing of its operation, he obviously would be impressed if the salesman were able to explain the structural features of the instrument designed to minimize energy transference in either direction by conduction, convection and radiation.

Cameras and photographic supplies offer an excellent opportunity to apply one's knowledge of optics. There is the question of the kind of an

instrument a particular customer should purchase, which involves consideration of the relative merits of different types in terms of structural features. After a purchase, questions arise as to how to get the best results with the camera and to make it applicable for different purposes under various conditions. True, literature on the subject is available, but the superiority of oral instruction and demonstration is obvious. The type of film to be employed, adjustment for varying object distances, relative aperture, time exposures and many other points need discussion. The customer usually returns for another course in instruction when he wants to take indoor pictures, do his own developing and printing, start taking moving pictures, and, always, when he gets into difficulties which lead to poor results. The analysis of his difficulties is an important (and usually easy) part of the salesman's job. Judicious use of the lens equation or a comparison of the *modus operandi* of the eye with that of the camera may often be made to serve very advantageously for this purpose.

In the early days of radio, many sets reached the consumer through drug channels. To a lesser extent this is still true, especially in small towns and communities where the clientele often turns to a druggist for a particular type of service not offered elsewhere. Even though the elaborate testing devices employed today in radio service tend to render the work empirical, nevertheless, it is my understanding that the elementary principles of radio and electricity are often applied.

An elementary knowledge of radiation is almost indispensable in the intelligent sale of a therapeutic lamp. As for electric clocks, I once saw a salesman sell one by making a rough drawing to show how it operated. (I think it was really the drawing the customer bought.) Many of us know how a well-known pharamaceutical house has made the general public "surface-tension-conscious" through extensive advertising of this physical property in relation to the germicidal activity of aqueous solutions; in fact, the preparation concerned was baptized S.T.37 because its coefficient of surface tension is 37 dyne/cm. One could go on for some time elaborating on other specific topics that afford the pharmacist definite opportunities to use his knowledge of physics in the commercial side of his business.

Displays of physical apparatus or processes can often be used to advantage in the store. They do not have to be elaborate; in fact, usually the simpler they are, the better they work. As a single example, a druggist once displayed a series of old x-ray plates and films. When the news got out, many people came expressly to see the display. A film showing an open safety pin lodged in a child's stomach created the most interest. The number and variety of such displays, as we all know, is practically unlimited, and the general interest in them is beyond question.

It has been my experience and observation that there is yet another important side to the story of the place of physics in the training of a pharmacist. The neighborhood druggist is the closest approach to a scientific man readily available to all members of the community. Think this over with regard to your own community, and I am sure you will find it so. This means that scientific news of the day is very often discussed in the store, and it affords the druggist a rare opportunity to build good will and a valued prestige. Recent submarine disasters provide a case to point—I do not remember how many times I was privileged to explain the method of calculating pressures beneath fluid surfaces. The close approach of Mars was another example; during dull hours it was a frequent topic of conversation. When helium makes the first page, one can be nearly certain that someone will bring up the relative advantages and disadvantages of it and hydrogen for lifting purposes. The importance of situations such as these is, I suppose, questionable; certainly their quantitative effects as builders of prestige and good will are difficult to measure. Judging from my own experience, however, I am inclined to believe that they can be extremely valuable, and, alone, would perhaps justify the inclusion of physics in the curriculum of a school of pharmacy.

No attempt at an exhaustive treatment of this subject has been made. A series of examples has been presented in an effort to show that the pharmacist has a definite need for certain phases of elementary physics in the daily practice of his chosen profession.

The Physics Building Project at the University of Mississippi

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THE building project in physics and astronomy recently completed at the University of Mississippi embraces two separate structures: a building for physics (Fig. 1) and an astronomical observatory (Fig. 2). The enterprise was financed with funds supplied by the State Building Commission supplemented by a P.W.A. grant; and represents a total investment of approximately $137,000, of which $42,000 was expended on the observatory.*

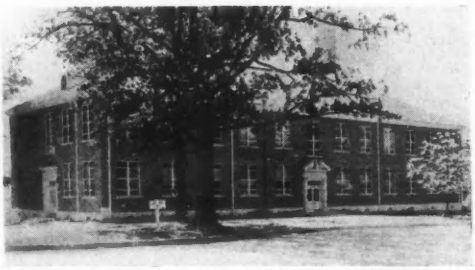

Fig. 1. Physics Building from the northeast.

Although the planning and supervision of this project consumed almost every available hour of the physics staff for more than a year, now that it is finished and the equipment installed, there seems to be little to be said about the result except that it measures up fully to our expectations. In describing the undertaking, it probably would be more interesting to recount the numerous joint sessions of our staff with the architects and their engineers prior to the actual drafting of the plans, for our experience convinces us that the success of an enterprise of this sort depends chiefly on what is done before actual building operations are begun. We do not mean to minimize the importance of high grade performance on the part of the contractors; but, granted one has a corps of competent, sympathetic and friendly architects, engineers and contractors, he will in the end get just about what he asks for. So the big determining factor in the success of the end-product is to know definitely and precisely in the beginning what one wants.

Our idea was not to construct an ornate building or one as spacious as funds would permit. Rather did we incline toward a streamlined model, with the idea that one cubic foot of space where you want it when you need it is more useful than a cubic yard of space where you do not want it when you do not need it.

The photographs and drawings of the Physics Building show the general form of the structure and the arrangement of the rooms. The main section of the building is rectangular (146×55 ft) with an extension (44×47 ft) in the rear. There are two principal floors, a floored attic and a basement; the last, owing to the topography of the terrain, is entirely above the ground level. The structure is of brick, tile, concrete and steel, and is of fireproof construction. The roof is of standard clay tile.

First Floor

The first floor (Fig. 3) houses the facilities for general physics, the administrative and staff offices, private laboratory rooms and certain other facilities. The general physics unit consists of a lecture room (47×44 ft), two recitation rooms (22×35 ft), a large laboratory room (36×53 ft), an apparatus room (37×22 ft) and a storage room (12×14 ft). It will be noticed (Fig. 3) that the general apparatus room com-

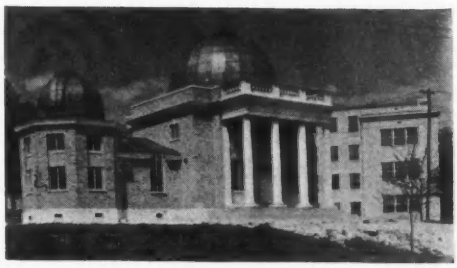

Fig. 2. Observatory from the southwest.

* The observatory will be described in a separate article.

municates directly with the lecture room, as well as with the laboratory, and is also accessible from the main corridor. Also, one classroom communicates directly with the laboratory. In this classroom is a well which extends across the rear of the room and through to the second floor ceiling to provide for such apparatus and experiments as require a high ceiling or vertical displacement.

At this point it is necessary to explain the relation of the housing units to our system of conducting laboratory work in general physics. Our program calls for the simultaneous performance of the same experiment by all members of a laboratory section. A large duplication of apparatus is necessary; but this, our experience for more than a quarter of a century has convinced us, is amply justified by the many outstanding advantages of the system. Under this system the laboratory section assembles in the classroom where the students receive oral instruction in amplification of the written directions, along with comments on special points of technic and necessary precautions. Often a set of the equipment which the class will use is placed on the instructor's table where the technic and the mode of assembly may be demonstrated. After this introduction, which usually requires from 10 to 20 min, the students repair to the communicating laboratory where they find all necessary apparatus at their working places. Ordinarily this is not assembled, as the assembling of the apparatus by the student is regarded as an essentially valuable part of the experiment. Occasionally, however, certain experiments are partially assembled when the students' working time might be unduly consumed and when little instructional value is involved. The students' time thus saved is utilized for the aforementioned preliminary instruction. We might add that the system of storing and handling[1] this equipment in specially designed containers and its distribution by means of service tables consumes very little of the instructor's time, and, besides, enables him to check all equipment for losses and injury almost instantly.

The general laboratory (Fig. 4) is equipped with 15 standard, 42×72-in. tables permanently located away from the walls. Ample space is provided between all tables so that the working

[1] Am. J. Phys. (Am. Phys. T.) **5**, 283–284 (1937).

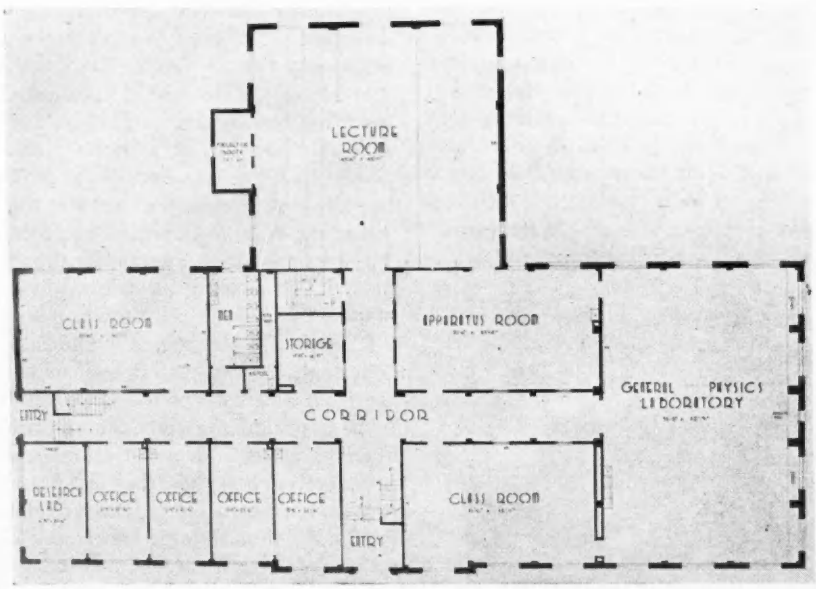

FIG. 3. First floor plan of Physics Building; scale, $\frac{1}{8}$ in. = 1 ft.

FIG. 4. Laboratory for general physics.

space on them is accessible from all four sides. Each table is provided with gas, compressed air and two electric outlets from which different voltages may be made available at one time. Water, sinks, balances and other facilities are provided around the side walls of the room. The room is provided with lightproof shades, forced ventilation, illuminated blackboards and unusual facilities for lighting, both natural and artificial.

Our standard laboratory section comprises 30 students working in pairs. Two pairs might work at a table without serious crowding, thus providing for 60 students per section; but the smaller sections are preferred. At the conclusion of the experiment, our system provides for assembling the class for the comparison and discussion of the results of their experiment.

In what we shall call the administrative section of the first floor the plans show 5 rooms, each 12×22 ft. One of these is assigned to the department head and communicating with it is another room of similar size which serves as a private laboratory. The other three rooms are assigned as offices to members of the staff. However, these rooms are really more than offices, as they are all serviced with gas, water, compressed air and experimental electric outlets. They are, therefore, all available for minor laboratory operations that require small equipment, or for the testing and construction of special instruments. The plans show a closet for janitor equipment, stock storage, toilet and other facilities conveniently available on this floor.

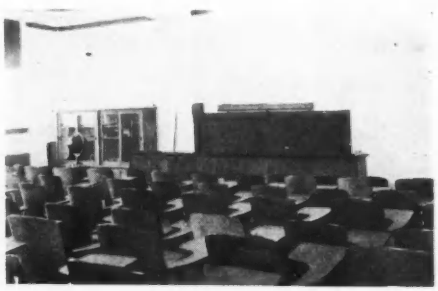

FIG. 5. Main lecture room.

LECTURE ROOM

The lecture room (Fig. 5), located in the rear center of the building, is readily accessible from the main entrance. This room has a ceiling height of 16 ft, is acoustically treated, and is provided with natural and artificial ventilation. In the design of this room four features were given special attention: seating arrangement, lecture table facilities, projection facilities and lighting.

Seating.—The room contains at present 131 pedestal tablet-arm chairs, rather widely spaced, and arranged in four blocks separated by two aisles. Each chair is easily accessible to the students without their stumbling against the feet and knees of others. The chairs are arranged in two rows at floor level, 2 rows at an elevation of 4 in., a third double row at another 4-in. elevation and, finally, single rows each at an additional 4-in. elevation. The back row is only 2 ft above the floor level; this provides ample elevation for viewing objects on the surface of the lecture table, if sufficient illumination is provided. When required, 36 portable chairs can be added to the room without blocking the aisles.

Lecture table facilities.—The lecture table is 16 ft long and is provided with all the usual facilities, particularly electric service. One feature of note (Fig. 6) is the provision for opening a 4-ft section in the center of the table to allow, if desired, the passage of the instructor between the front and back of the table without having to pass around the ends. This is convenient in making certain demonstrations, though the primary purpose of the arrangement is to provide for the use of a blackboard globe required in connection with large astronomy classes. The technic of using a three-dimensional blackboard is quite different from that of the flat surface. The three-dimensional board requires that the

instructor be able to approach it from all directions and, at the same time, to be able to transfer much of his material in projection onto the flat board; hence, the need of free communication between the two without the obstruction of a lecture table.

Projection facilities.—The projection room in the rear of the lecture room is 14×7 ft, ample to house all the usual types of projection equipment in permanent position ready for use, as well as to house slides, reels and all accessories. The room is fireproof with two metal-covered doors. In case a reel catches fire the operator merely needs to step out of the nearest door and close it; within a few minutes he can return in safety to inspect the damage. A large observing port is provided which gives the operator full view of his audience. A microphone in the projection room connected with a loudspeaker near the lecture table enables the operator, usually the instructor, to comment freely on the slides or reels, or to conduct an illustrated lecture single handed without having to bring the equipment out into the lecture room.

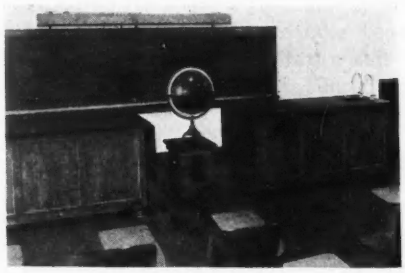

FIG. 6. Detail of lecture table.

The blackboard in the lecture room and those throughout the building are equipped with hooded fluorescent tube illuminators mounted directly above the boards. The wall above the blackboard is surfaced as a high grade screen. With this arrangement the room may be darkened and still allow the lecturer free use of the illuminated blackboard without interfering with the visibility of the projected material.

LIGHTING FACILITIES

The first item on which our staff all agreed offhand was that every room in the building should be amply provided with both daylight and artificial illumination. Adequate artificial illumination is easy to arrange, provided it is not

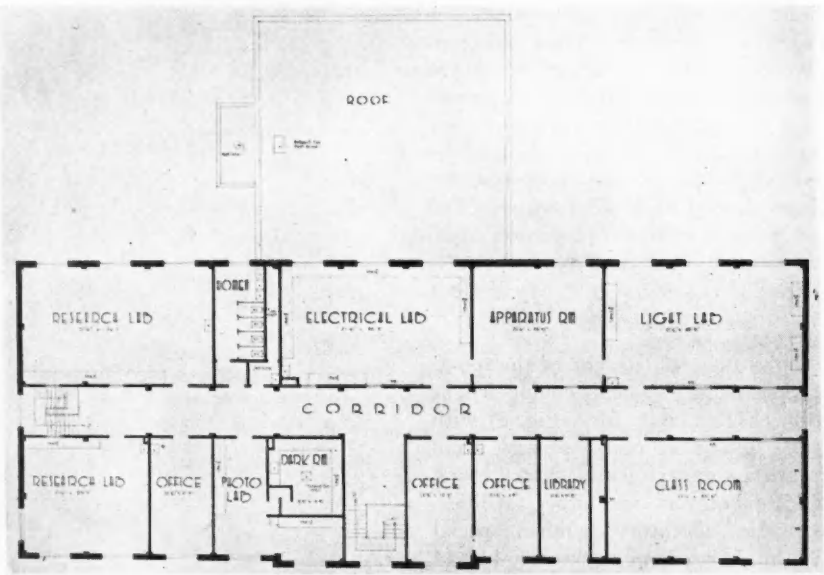

FIG. 7. Second floor plan of Physics Building; scale. $\frac{1}{8}$ in. = 1 ft.

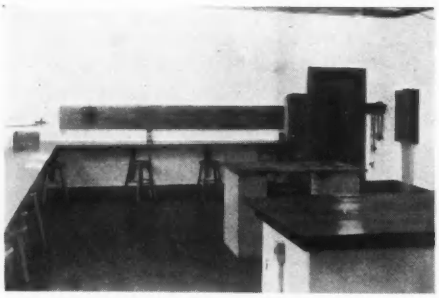

FIG. 8. Electric laboratory.

overlooked. The illumination adopted is semi-indirect with careful attention to distribution, and is provided in more than ample quantities. For example, in the general physics laboratory there are 15 fixtures each of 200 w. This provides a measured illumination of 6 ft-c on the table surfaces. Daylight illumination in the center of the room measured under favorable conditions is also 6 ft-c.

Daylight illumination is not so easily managed. Fortunately, in our latitude the high altitude of the sun between 9 A.M. and 3 P.M. for the greater part of the year, together with the prevailing clear skies and atmosphere, is sufficient to provide an abundant supply of light without the use of skylights, if enough window space is available. Moreover, the axis of our building is east and west, and thus we have the advantage of the best exposures. Since the window space is ample, the daylight illumination even in the corridors is ample. In the lecture room, for instance, there are 300 ft² of window area. The windows are of the steel-frame projection type, which allows satisfactory natural ventilation.

SECOND FLOOR

Figure 7 shows the arrangement of the rooms on this floor, there being a specially equipped light laboratory, an electric laboratory (Fig. 8) with communicating apparatus room, several small office-laboratories, a departmental library room, a photographic laboratory and other facilities. The photographic laboratory requires special comment. Within it is a large darkroom, 14×14 ft, in which there is ample working space for four students at a time, and roomy facilities for development, enlargement and all the usual photographic requirements. Artificial ventilation is provided. The crowded space and stuffy conditions so frequently encountered in photographic darkrooms are entirely avoided. A maze provides passage between the laboratory and the darkroom without the necessity of opening doors or otherwise interfering with work in the darkroom. The illustrations in this article are all from photographs made by the class in photography.

In an earlier part of this article it was intimated that every square foot of space in the building was planned to yield maximum usefulness. This applies to the long, wide, unobstructed corridor (9×140 ft) on this floor. Ordinarily only advanced students work on the second floor; hence this corridor is not subject to heavy passageway traffic. It was designed with a view to

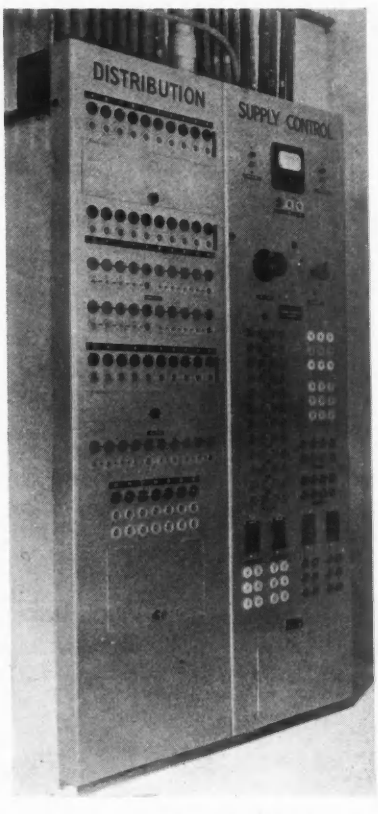

FIG. 9. Main supply and distribution board.

providing opportunity for experiments where communicating parts of apparatus require wide separation; thus it serves, also, as an integral laboratory space. The large windows at the two ends of this corridor and at the entrances afford good daylight illumination.

Attic and Basement

The attic over the entire main section of the building is floored, and available for certain uses. It is not serviced with utilities.

The principal basement is located beneath the lecture room and has the same dimensions. It contains a well-equipped shop (18×30 ft), a general utility room (22×29 ft), a generator room with main distribution panels, a gas-machine and battery room, and a corridor. Beneath the entire main section of the building is an unfloored space, partially available for future development. The basement is accessible at ground level in the rear and from the corridor of the first floor.

Experimental Electric Circuits

Electric circuits are made available from the central board in the generator room (Fig. 9) to secondary panels (Fig. 10) in the various laboratories and, thence, to the outlets on the tables. Utility outlets are also provided in the baseboards throughout the building. All experimental circuits are in metal conduits.

Ceiling, Walls and Floors

The ceilings of the lecture room and the three recitation rooms are surfaced with 1-in. acoustic tile applied according to government specifications.

All walls are plaster with white gypsum surfaces. This plaster is applied to tile or brick as the case might be. In order that instruments and other objects may be supported without seriously defacing the plaster walls, a heavy 5-in. picture molding attached to blocks set in the tile or brick walls is supplied throughout the building (Fig. 5). These moldings will support weights of several hundred pounds. Also wall-boards $1\frac{1}{4}$ in. thick, 16 in. wide, attached by means of machine bolts set in the walls, are provided in all laboratories (Figs. 4 and 8) for mounting wall instruments; these boards are readily removable and can be replaced when and if they become defaced by long usage. Slotted key-ways of metal set in the ceiling slabs provide for bolts from which objects may be suspended from the ceilings.

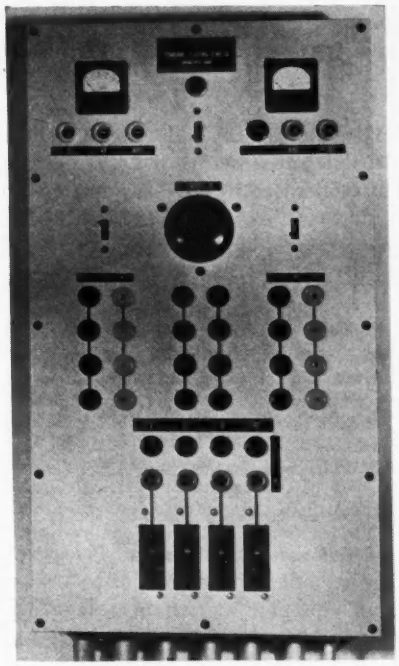

Fig. 10. Secondary distribution board.

All floors are surfaced with acid-resisting composition tile. We emphasize the acid-resisting quality somewhat facetiously because all dealers in these materials insisted on demonstrating this feature. As all physicists know, acids are rather rare commodities in the physics laboratory; whereas oils, greases and hot objects have a rather uncanny way of getting in contact with laboratory floors. Many composition tiles which show amazing resistance to acids melt away rather readily when exposed to oils and high temperatures.

Conferences on Nuclear Physics

Massachusetts Institute of Technology, sponsored by the American Institute of Physics, Cambridge, Mass., Oct. 28–Nov. 2.

Indiana University, Bloomington, Oct. 25–26.

Proposal to Standardize Letter Symbols

REPORT NO. 3 OF THE COMMITTEE ON LETTER SYMBOLS AND ABBREVIATIONS

WHILE the Greeks undoubtedly had a word for it, no lesser person than Alice was the first modern to record bewilderment at the "ways that are dark and the tricks that are vain" [1] in the wonderland of symbols.

> "They were learning to draw," the Dormouse went on, yawning and rubbing its eyes, for it was getting very sleepy; "and they drew all manner of things—everything that begins with an M . . . , such as mouse-traps, and the moon, and memory, and muchness—you know you say things are 'much of a muchness'—did you ever see such a thing as a drawing of a muchness!"
>
> "Really, now you ask me," said Alice, very much confused, "I don't think—"
>
> "Then you shouldn't talk," said the Hatter.

Alice's reaction was akin to the perplexed irritation of students today when trying to master an equation written in a language for which the author appends no dictionary. Indeed, sometimes a symbol list cannot be constructed without correcting the inconsistencies in the body of the text. At best, the abstract thinking in physics remains almost entirely alien to some students who, in later life, make decisions affecting society that would be better for the application of physical reasoning. The language of physics—terminology, symbols and abbreviations—is, more often than necessary, an unsurmountable barrier to the attainment of that view which Eddington expresses so cogently.[2]

> Science aims at constructing a world which shall be symbolic of the world of commonplace experience. . . . The symbol *A* is not the counterpart of anything in familiar life. To the child the letter A would seem horribly abstract; so we give him a familiar conception along with it. "*A* was an Archer who shot at a frog." . . . In physics we have outgrown archer and apple-pie definitions of fundamental symbols.

The history of symbol standardization[3]

The object of standardization of symbols used in mathematical formulas is to eliminate, or at least to minimize, the language impediment. When all authors use the same symbol for a magnitude, students will soon become familiar with it and will be saved a lot of puzzling. Fortunately, there is no longer the feeling that once existed that it is a beneficial training of the mind to puzzle over the symbols and other language of an author. Now most people agree that symbol standardization really provides a desirable economy in mental effort.

Electrical science and engineering fortunately have escaped many of the aforementioned difficulties because of early standardization of symbols by the International Electrotechnical Commission. In 1914, the I.E.C. issued Fascicule 27 on this subject, which was revised in 1920. The symbols standardized in these documents have been adhered to closely by the American Institute of Electrical Engineers, by similar bodies in other countries, and also are used by nearly all authors. At a meeting of the I.E.C. in the summer of 1938 at Torquay, England, some additions and clarifications were made in the standard electric symbols and a new list now awaits issuance. However, the troubled international situation is causing disturbances much more serious than the delay in the publication of this international list. In the meantime, an American standard which closely conforms to the expected International Standard is being arranged by the American Institute of Electrical Engineers and A.S.A. Subcommittee No. 8 described below.

The constitution of the I.E.C. Subcommittee on Letter Symbols, as appointed in Scheveningen in 1935, is: W. BÄNNINGER, Switzerland; A. CURCHOD, France; G. GIORGI, Italy; E. W. MARCHANT, Great Britain; J. F. MEYER, U. S. A.; J. WALLOT, Germany; J. WENNERBERG, Sweden (chairman).

The year 1914 also witnessed the formation of a Committee on Standardization of Technical Nomenclature of the Society for the Promotion of Engineering Education which, under the chairmanship of J. T. FAIG, proposed in 1917 a

[1] From Bret Harte's, "The heathen chinee."

[2] A. S. Eddington, *The nature of the physical world* (Macmillan), p. xiii.

[3] This section of the report was prepared by Dr. Sanford A. Moss, General Electric Company.

list of standard letter symbols for mechanics and hydraulics.

In 1926, a Sectional Committee on Scientific and Engineering Symbols and Abbreviations was organized by the American Standards Engineering Committee (predecessor of the American Standards Association) sponsored by five societies as follows: The American Association for the Advancement of Science, The American Institute of Electrical Engineers, The American Society of Civil Engineers, The American Society of Mechanical Engineers and the Society for the Promotion of Engineering Education. The reports of the subcommittees of this Sectional Committee were adopted as American Tentative Standards or as American Standards at various times, some by the original American Standards Engineering Committee and some by its successor, the American Standards Association. When in 1936 it was thought desirable to revise the standards that had been issued by the original Sectional Committee, the scope of its work was broadened in some respects and narrowed in

Dr. Sanford A. Moss, the father of symbol standardization in the United States and an ardent supporter of international standardization. He is vice chairman of the A. S. A. symbol project.

others. It was broadened in respect to the subjects included so far as letter symbols were concerned but narrowed by the exclusion of all reference to graphical symbols which had constituted a considerable part of the work of the original Sectional Committee. J. FRANKLIN MEYER of the National Bureau of Standards is now chairman. The American Association of Physics Teachers became associated with the project in July, 1937, when the same personnel as constitutes its Committee on Letter Symbols and Abbreviations accepted appointment from the A.S.A. as Subcommittee No. 10 on Physics. All of these committees are working busily, and some of them have issued drafts of new lists. These will shortly go through the regular procedure for American standardization provided for by the rules of the A.S.A. The A.S.A. subcommittees and their chairmen are as follows:

1. *Mathematics.* ALBERT A. BENNETT, Brown University.
2. *Hydraulics.* J. C. STEVENS, 1202 Spalding Building, Portland, Oregon.
3. *Mechanics of Solid Bodies.* R. E. PETERSON, Westinghouse Research Laboratories.
4. *Structural Analysis.* ALBERT HAERTLEIN, Harvard University.
5. *Heat and Thermodynamics.* SANFORD A. MOSS, General Electric Company.
6. *Photometry.* E. C. CRITTENDEN, National Bureau of Standards.
7. *Aeronautics.* G. W. LEWIS, National Advisory Committee for Aeronautics.
8. *Electric and Magnetic Quantities.* J. FRANKLIN MEYER, National Bureau of Standards.
9. *Radio.* H. M. TURNER, Yale University.
10. *Physics.* HAROLD K. HUGHES, University of Newark.
11. *Abbreviations.* G. A. STETSON, editor of A.S.M.E. publications.

The American Association of Physics Teachers is also associated with the National Research Council through interlocking membership on its recently formed (June, 1940) Committee on the Standardization of Symbols and Abbreviations of the Division of Chemistry and Chemical Technology. The chairman is CHARLES A. MARLIES of The College of the City of New York.

Mere American standardization will only partially accomplish the result sought. The I.E.C. has achieved standardization in its own field, but similar progress in other fields has not yet been found possible. There are many reasons for believing that international standardization of symbols in general is going to be a very difficult matter. However, the A.S.A. and the British Standards Institution have discussed the proposition of trying to standardize symbols in most branches of science and engineering for the English language. This would involve coopera-

tion of subcommittees in various individual fields in the British Empire and America. Even this is going to be difficult enough, although plans for overcoming the difficulties were under way when the present war caused postponement of the cooperative project. American standardization is going forward, and the large use of English textbooks in the United States requires that the American standards take due note of English customs. Then, when more propitious times arise, the American standards will not need much revision in order to provide the hoped-for standards for the English language.

Procedure; sources consulted

Physical journals, textbooks and reference works were searched during the preparation of Report No. 2 of the present committee. Following the presentation to the Association of this factual survey of current usage, of which about 200 mimeographed copies were distributed, a file card was prepared for each quantity and upon it was entered all comments received and all symbols in use. In addition, the proposals of all other symbol committees, both in the United States and abroad, were recorded on the appropriate card. The reports of other committees, such as the Association's Committee on Electric and Magnetic Units[4] and the Optical Society of America Colorimetry Committee,[5] were scrutinized for symbol practice. The committee studied this master list carefully, first the non-controversial symbols and then the controversial symbols. The present report, No. 3, records its tentative recommendations.

Copies of the reports of other A.S.A. symbol committees are available (or will be available when completed) from the American Standards Association, 29 West 39 Street, New York City. The report of the Joint Committee of The Chemical Society, The Faraday Society and The Physical Society may be obtained from the Assistant Secretary, The Chemical Society, Burlington House, Piccadilly, London, W.1.

The committee approves of the request of the A.S.A. that communications to foreign standardizing bodies be sent by the A.S.A. through the International Standards Association. This is necessary in order to keep the I.S.A. informed of all efforts at cooperation among its members and to avoid creating the impression among other nations of anything that would indicate an "Anglo-American bloc."

[4] "What is the meter-kilogram-second system of units?", Am. J. Phys. (Am. Phys. T.) **6**, 144 (1938).

[5] L. A. Jones, "Colorimetry: Preliminary draft of a report on nomenclature and definitions," J. Opt. Soc. Am. **27**, 207 (1937). See also "Terms used in radiation measurements," Rev. Sci. Inst. **7**, 322 (1936) and A. G. Worthing, "Radiation laws describing the emission of photons by black bodies," J. Opt. Soc. Am. **29**, 97 (1939).

General principles of symbol standardization

At a meeting in New York on November 1, 1939, the Steering Committee of the A.S.A. Sectional Committee Z10 adopted a list of "General Principles," substantially as follows, which your committee helped to formulate and to which it subscribes.[6]

1. When an author is preparing a manuscript, it is suggested that he give careful attention to the use of symbols from this list and to the principles here given.

2. Letter symbols are letters used to represent magnitudes of physical quantities in equations and mathematical formulas. They are to be distinguished from the following:

(*a*) *Abbreviations*, which are shortened forms of names or expressions employed in texts and tabulations, and which should not be used in equations.

(*b*) *Mathematical signs* and *operators*, which are characters used with letter symbols to denote mathematical operations to be performed.

(*c*) *Graphical symbols*, which are conventionalized diagrams or letters used on plans and drawings.

3. Typography. Letter symbols and letter subscripts, whether upper or lower case, should be printed in inclined or italic type unless definitely specified otherwise. Special types, such as Old English and type that is currently used for vector quantities, should be avoided for scalar quantities. When special type is used for vectors, etc., the same letter in italics should be used as the symbol for the corresponding scalar magnitude. Vertical Arabic numerals should be used as coefficients in equations and as subscripts and exponents. Bars, dots and other modifying signs should not be used except in the manner currently recognized by mathematicians.

4. A *single letter* should be used to represent each magnitude, with subscripts or superscripts if required. Two or more letter symbols together should always represent a product.

5. Symbols used should be defined clearly. When a table of symbols[7] is not given, it will often be helpful if reference is made to the standard lists from which the

[6] The wording is slightly different from the original in a few minor cases. For example, we have removed from the original list, as adopted by the A. S. A., the proscription on script letters. A majority of the members who attended the annual meeting of the Association in Washington, Christmas, 1938, supported the use of script letters. The committee has found this additional font very helpful on occasions, as will be seen from a perusal of its tentative list of symbols.

[7] For an excellent illustration of the use of a table of symbols in a journal article, see Suits and Poritsky, "Application of heat transfer data to arc characteristics," Phys. Rev. **55**, 1184 (1939).

symbols are taken. The same symbol should be used regardless of particular units, and the units used should be indicated when necessary.

6. Special symbols may be selected for magnitudes not appearing in standard lists, either by using a standard symbol with an appropriate subscript or by selecting a new letter.

7. The *identical symbol* used in one standard list for a certain magnitude often appears for a different magnitude in another standard list covering a different field. A text using two or more such magnitudes may avoid duplication in one of the following ways:

(*a*) For one or more of the conflicting uses, the given symbol may be employed with subscripts selected by the author;

(*b*) If the symbols have alternates in the standard lists, one of them may be used;

(*c*) A slight change in the name of the magnitude may remove the conflict. For instance, one may use l for "length of radius," when r for "radius" conflicts with r used for another magnitude.

8. The *same symbol* should be used for the *same magnitude* regardless of special values occurring for different states, points or parts. Subscripts or superscripts may be used to distinguish between different units, states, points or parts, or, when both are standardized, upper and lower case letters may be used. (*Cf.* paragraph 1 of the next section.)

9. Superscripts, such as the primes, ′ and ″, and exponents, may be used at the same time. The symbol with superscripts should then be placed in parentheses before taking the exponent. Superscripts should be distinguished from reference marks.

10. Subscripts preferably should be single symbols. Multiple subscripts, sometimes separated by commas, indicate reference to several states, points or parts. Subscripts may be added to standard symbols to distinguish different units, to denote particular values, to distinguish between conflicting symbols and to form symbols for new magnitudes. Letter subscripts are also used to indicate constancy of a particular magnitude, such as pressure or temperature, when there are other variables.

11. Only when *upper* and *lower case letters* appear in standard lists as optional symbols of equal rank for the same magnitude should they be used to distinguish between different values of the magnitude for different units, states, points or parts.

12. Manuscript should present letter symbols so that they will not be misread by the compositor. It should be indicated clearly which one of the many letters, numbers and signs, that are similar in appearance, is meant in each case. Exponents, index numbers to references and superscripts should be distinguished clearly. A complicated exponent or expression frequently repeated may be replaced by a single symbol selected to represent it.

The committee urges the adoption of these general principles by all persons interested in symbol standardization.

Additional principles and attitudes

As cases arose during the progress of the work that were not covered by the foregoing guides, the committee regularized its choices with the following additional principles:

1. It is understood that all letter symbols, when not operators, represent measures of physical quantities; that is, the symbol is equivalent to a pure numeric and units. The numeric is always the modulus value in the case of fixed constants. Thus, e is the symbol for the charge of the positron and $-e$ the symbol for the electronic charge. The same symbol is employed regardless of units. Where it is necessary to indicate the units for a magnitude or the system of units for an equation, subscripts are often convenient or the reference number of the equation may carry in addition to the numerals a letter designating the unit system. Dow in his *Fundamentals of engineering electronics* makes very successful use of the latter device, employing m, s and p to indicate the electromagnetic, the electrostatic and the practical system of units, respectively. Thus on page 173, all quantities placed into Eq. (329p) are to be in practical units.

2. Vectors and *dyadics* should be printed in boldface type. On a manuscript, this is shown by placing a wavy line under each such symbol.

3. The *Cartesian coordinate system* should always be right-handed and the axes specified by the capital letters X, Y and Z in Roman type. No one orientation of the axes is proposed.

4. Operators, such as sin, cos, tan, D, exp, etc., are printed in Roman type.

The committee has studied, but has not acted upon, a number of other proposals put forward to systematize the choice of letter symbols.

Foremost among these is the desire by some to use lower-case letters for all "specific" quantities, that is, values per unit length, per unit mass, etc. One example is found in acoustics where the symbols for several magnitudes follow this plan. Again, the "Proposed Revision of American Standard for Letter Symbols for Electric and Magnetic Quantities," issued March, 1940, contains the statement: "It is recommended that quantities per unit volume, area, length, etc., be represented as far as practical by lower-case letters, corresponding to upper-case letters which will represent the total quantities." This rule cannot be applied universally. In electrical engineering, for example, capital letters for effective values and small letters for instantaneous values are deeply rooted.

A scheme to employ black-face italic type for important physical constants, which it is claimed will lighten the burden on certain letters, is being pushed with considerable vigor by H. J. T. ELLINGHAM of the Imperial College of Science and Technology, England. Included in the list which the "Report of a Joint Committee of The Chemical Society, The Faraday Society, and The Physical Society" recommends are: Avogadro number, Boltzmann constant,

modulus of electronic charge, Faraday constant, Planck constant, speed of light. The British Standards Institution and The Royal Society have also endorsed this proposal.

The subscript $_n$ finds favor among a few commentators to indicate *minimum* values. Note that the recommendation is for $_n$, not $_m$.

Another proposal received by the committee relates to the needs of undergraduate and advanced students: "Whenever possible, the symbol for a quantity should be one that remains convenient in advanced writings in the field concerned rather than one designed to suit the casual reader."

The system which may be recommended by the newly formed chemistry committee to designate values of a quantity per mole, per unit mass, per molecule, and the total value is illustrated in the main list below under the entry "fusion, heat of." Our committee is not proposing this usage and includes these entries only in the hope of evoking discussion.

A.S.A. Subcommittee No. 5 proposes the following special principles applying primarily to heat and thermodynamics:

1. Letter subscripts are customarily used to denote particular values of a magnitude for different phases, states or physical conditions. *Numerical subscripts* are customarily used to denote values of a magnitude for different points in an apparatus, process, or cycle, which may be either different locations or geographic positions, or else different instants of time.

2. A letter symbol alone or with a single subscript represents a magnitude, often at a particular state or physical condition. It should not be used by itself or with the addition of a bar, or the like, to denote a variable change in a magnitude, or a difference between two values.

3. The *differential* of a variable x should be represented by dx for an increase and by $-dx$ for a decrease.

4. Finite increments of a variable x should be represented by Δx or by $-\Delta x$. A finite increase from point 1 to point 2 may be represented by a double subscript such as $(\Delta x)_{1,2}$ or $(\Delta x)_{1\to 2}$ meaning x_2-x_1, or, if no confusion can arise, by an expression such as x_{ab} meaning x_b-x_a. Sometimes it is necessary to specify the path taken between two points.

5. A double letter subscript only, without the use of the operator Δ, is in current use to represent an invariable difference between two independent physical states, such as the change from a liquid to a gas. Thus H_{fg} is the difference in enthalpy between that for vapor and that for liquid at saturation temperature.

6. A chemical reaction in which heat is absorbed or given out requires a symbol for this amount of heat, on the basis of a given temperature of the constituents and the same or different temperature of the products. Such temperature or temperatures must be given by subscripts or otherwise. This is regardless of any intermediate temperature which may be attained during the reaction.

Omissions from this report

In the case of specialized or rapidly developing fields where the number of workers is relatively small, a magnitude is listed only if it is well established and there is already some agreement on its symbol. Quantities in relativity and crystal physics and those generally handled with tensors and spinors are thus omitted.

While there have been requests for standardized signs for arithmetic operations, the committee feels that this matter should be settled by the mathematics committee. To that committee is also left the subject of boldface type for complex quantities.

Symbols, such as $_0n^1$ for neutron, are not letter symbols in the sense of this report but rather chemical symbols of the same character as Ag, O_2, etc.

Tentative List of Letter Symbols and Operators

The following compilation is cross-indexed and it is hoped that all equivalent terms employed in undergraduate physics are included here or in the Supplementary List section of this report. Since success in the simplification of symbol conventions depends directly upon the number of persons criticizing the list as well as using it, the committee will welcome and will examine fully all suggestions for improving the effectiveness of the list and gaining for the final report an increased degree of acceptance among authors and editors.[8] Please address communications to the chairman at Pupin Physics Laboratories, Columbia University, New York City.

Symbols separated by commas are alternates of equal weight. Reserve symbols whose use is discouraged are in parentheses.

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[8] To each paper received by the American Society of Civil Engineers, for publication in *Civil Engineering* or in the *Proceedings* and in the *Transactions*, is attached a four-page form headed "Standard Notation." The pages are ruled horizontally and a separate line devoted to each upper- and lower-case Roman and Greek letter which is placed at the left edge. The editor jots down the symbol definitions as he reads the paper and notifies the author of inconsistencies.

A

absolute humidity ..... ρ
absolute temperature ..... T, (Θ)
absorption or absorption factor $[=F_a/F_i]$ ..... α
absorption coefficient $[I_x=I_0 \exp(-ax)]$ ..... a
  for a room, mean (acous.) ..... a
  of absorbing material (acous.) ..... α
absorption index $[=(\lambda/4\pi x) \ln I_0/I]$ ..... κ
acceleration, angular ..... $\boldsymbol{\alpha}$
acceleration, gravitational ..... g
  45° value $[=980.616 \text{ cm sec}^{-2}]$ ..... g_{45}
  local value ..... g_L
  standard value $[=980.665 \text{ cm sec}^{-2}]$ ..... g_s
acceleration, linear ..... $\mathbf{a}$
accommodation coefficient ..... a
acoustic:
  conductivity of an opening c
  equations for forced oscillations with velocity damping
    $m\ddot{x}+r\dot{x}+(x/C)=F\cos\omega t$; $\ddot{x}+2k\dot{x}+n^2x=a\cos\omega t$
  impedance ..... Z
  impedance, specific $[=Z/A]$ ..... z
  intensity (e.g., erg cm^{-2} sec^{-1}) I
  reactance X
  reactance, specific $[=X/A]$ x
  resistance ..... R
  resistance, specific $[=R/A]$ ..... r
  source, strength of simple ..... A
action ..... S
action variable ..... J
activity at time t (radioactivity) I
activity, chemical ..... a
activity, initial (radioactivity) ..... I_0
adiabatic exponent $[pV^\gamma=\text{const.}]$ ..... γ
admittance or reciprocal impedance ..... Y
  grid or input (with plate load) $[=g_g-\mathrm{j}b_g]$ ..... y_g
  plate or output $[=g_p-\mathrm{j}b_p]$ ..... y_p
adsorbed ..... subscript a
affinity, electron $[\mathrm{d}\varphi=\mathrm{d}w/\mathrm{d}q \text{ volts}]$ ..... φ
  gross electron ..... φ_g
altitude ..... h, (y)
amplification factor $[=-(\partial v_p/\partial v_g)_{i_p}]$ ..... μ
amplification factor, gas (photoelectric tube) ..... μ
amplification of amplifier, power ..... A, A_p
  voltage ..... A, A_v
amplitude ..... A
  of simple harmonic pressure (acous.) ..... P
angle:
  azimuth (optics) ..... ψ
  between ray and normal in first medium ..... φ
  between ray and normal in second medium ..... φ'
  critical ..... φ_c
  epoch ..... ϵ, (φ)
  glancing ..... θ
  of contact ..... θ
  of deviation ..... δ
  of diffraction ..... θ
  of incidence, principal ..... $\bar{\varphi}$
  of minimum deviation ..... D
  of optical rotation ..... θ
  phase ..... φ
  plane ..... θ, (α, β)
  polar coordinate ..... θ
  polar (colatitude) ..... θ
  polarizing, or principal angle of incidence in dielectrics . $\bar{\varphi}$
  principal azimuth ..... $\bar{\psi}$
  refracting, of prism ..... A
  solid ..... ω
angles, spherical coordinates .....
    θ (=colatitude), φ (=longitude), λ (=latitude)
angular:
  acceleration ..... $\boldsymbol{\alpha}$
  dispersion $[=\mathrm{d}\theta/\mathrm{d}\lambda]$ ..... D
  displacement ..... $\boldsymbol{\theta}$
  distance ..... θ
  frequency of free vibration with damping ..... ω', (n')
  frequency of impressed force ..... ω, (p)
  frequency without damping ..... ω, (n)
  frequency, or periodicity or angular speed $[=2\pi f]$ ..... ω
  magnification $[=\tan u'/\tan u]$ ..... γ
  resolving power of telescope ..... α
  speed ..... ω
  velocity ..... $\boldsymbol{\omega}$
aperture (optics) ..... a
arc length ..... s
area ..... A, S, σ
  moment of $[=\int y\mathrm{d}A]$ ..... Q
  of cross section, walls (acous.) ..... S
associated Legendre polynomial or spherical function $[P_{l,m}(\theta) \exp im\varphi]$ ..... $Y_{l,m}$
atomic number ..... Z
atomic volume V
atomic weight ..... A
attenuation, optical ..... D
attenuation constant $[\gamma=\alpha+\mathrm{j}\beta]$ ..... α
average value .....
    Use bar over symbol, or subscript $_{av}$ (e.g., $\bar{I}$, I_{av})
Avogadro number (no./gm-mol) ..... N, N_0
azimuth angle (optics) ..... ψ
  principal ..... $\bar{\psi}$

B

base of natural logarithms $[=2.718\cdots]$ ..... , exp, ϵ, e
beam deflection or sag ..... δ
Bohr magneton $[=eh/4\pi mc)$ ..... μ_0
Bohr radius $[=h^2/4\pi^2me^2]$ ..... a_1
Boltzmann constant ..... k
Boltzmann function $[=\sum_i n_i \ln n_i]$ ..... H

Bragg planes in a crystal, spacing of ..... d
Bragg reflection indices .... $h_1[=nh]$, $h_2[=nk]$, $h_3[=nl]$
breadth or width ..... b
brightness $[=\mathrm{d}I/\mathrm{d}A\cos\theta]$ ..... B

C

candlepower or luminous intensity $[\mathrm{d}F/\mathrm{d}\omega]$ I
capacitance or permittance C

capacitance, partial ..... c (with suitable subscripts)
capacitance, reciprocal, or elastance ..... S
capacitive reactance ..... X_C
capacitivity or dielectric coefficient ..... ϵ
capacitance, specific inductive, or relative dielectric coefficient ..... ϵ, ϵ_r
cathode ..... Attach subscript $_c$ to symbol
Cauchy constants $[n=A+B/\lambda^2+C/\lambda^4]$ ..... A, B, C
change operator, small finite ..... Δ
charge density, linear ..... λ
surface ..... σ
volume ..... ρ
charge, quantity of electric ..... q, Q
modulus of electronic ..... e
chemical potential $[\partial G/\partial n]$ ..... μ
circle of least confusion, radius of ..... Z
circular frequency $[=2\pi f]$ ..... ω
coefficient of accommodation ..... a
coefficient of friction ..... μ
(Use f if μ designates the Poisson ratio.)
rolling ..... μ_r
sliding or kinetic ..... μ, (μ_k)
starting or static ..... μ_s
coefficient of recombination ..... α
coefficient of resistance, temperature ..... α
coefficient of restitution or resilience ..... e
coefficient of thermal expansion or expansivity of a gas .. α'
coefficient, potential ..... p
colatitude ..... θ
collision diameter of molecule ..... σ
collision frequency, molecular (no./time) ..... Z
complex conjugate ..... Use an asterisk * as superscript
compliance C
compressibility, coefficient or factor of ..... k, κ
concentration, molecular, or molecular density $[=\text{no./cm}^3]$ ..... n
concentration (solutions) c
condensation (acous.) ..... s
conductance, electric ..... G, g
grid or input ..... g_g
grid, at zero frequency and constant plate potential $[=(\partial i_g/\partial v_g)_{v_p}]$ ..... k_g
plate or output ..... g_p
plate, at zero frequency and constant grid potential $[=(\partial i_p/\partial v_p)_{v_g}]$ ..... k_p
thermal ..... $1/R$
conduction current I
conductivity, electric $[\mathbf{i}=\sigma\mathbf{E}]$ ..... σ, κ, γ
equivalent (mho/mole) ..... Λ
molecular ..... μ
of an opening (acous.) c
thermal ..... k
configuration-space volume V
conjugate, complex ..... Use an asterisk * as superscript
contact or Volta potential ..... V_v
continued product ..... Π
contrast of photographic emulsion ..... γ
control ratio, grid (thyratrons) ..... μ
convection current ..... I, ρv
coordinates, cylindrical ..... r, θ, z, (y)
displacement of sound-bearing particle ..... ξ, η, ζ
generalized ..... q
generalized curvilinear ..... ξ, η, ζ
moving Cartesian axes ..... ξ, η, ζ
polar ..... r, θ
rectangular ..... x, y, z
spherical ..... r
θ (=colatitude), λ (=latitude), φ (=longitude)
coupling coefficient ..... k, τ
critical angle ..... φ_c
critical pressure ..... p_c
critical properties ..... Attach subscript $_c$ to symbol
critical temperature ..... t_c, T_c
critical volume ..... V_c
crystal planes, spacing of Bragg ..... d
cubic coefficients $(x^3+ax+b=0)$ ..... a, b
cubic discriminant $[=(b^2/4)+(a^3/27)]$ ..... Δ
curl operator ..... $\nabla\times$
current, average ..... $\bar{I}$, I_{av}
conduction I
convection ..... I, ρv
displacement ..... $\dot{\mathbf{D}}$, $\dot{\mathbf{D}}/4\pi$
instantaneous ..... i, (I)
maximum ..... I_m, (I_{max})
peak ..... $\hat{I}$, (I_{pk})
quiescent ..... I_Q
rms or effective I
saturation ..... I_s
steady direct I
current efficiency $[=I_{useful}/I_{total}]$ (electrolysis) ..... η_I
curvature ..... K
radius of ..... ρ
curvilinear coordinates, generalized ..... ξ, η, ζ
cylindrical coordinates ..... r, θ, z, (y)

D

D'Alembertian operator ..... $\Box$
damping factor, velocity. *Cf.* acoustic equations for forced oscillations with velocity damping
decay constant $[N=N_0\exp(-\lambda t)]$ ..... λ
decay modulus $[s=A\cos(\omega t+\varphi)\exp(-t/\tau)]$ ..... τ
deflection of beams, of galvanometer, etc. ..... $\bar{u}$
degeneracy (statistical weight) ..... g
degree of dissociation or ionization (electrolytes) ..... α
degree of hydrolysis (electrolytes) ..... h
degrees of freedom (kinetic theory and Gibbs phase rule) f
density $[=m/V]$ ..... ρ, (D)
density, linear (m/l) ..... λ, (ρ)
mass or volume $[m/V]$ ..... ρ, (D)
molecular (0°C, 1A$_s$) or Loschmidt number ..... n_0
molecular, or molecular concentration [no./cm^3] .... n
optical $[=\log_{10} I_0/I]$ ..... D
relative ..... D
standard (referred to $g_s=980.665$ cm sec^{-2} at 0°C, 1A$_s$) ..... ρ_s, (L)
surface $[m/A]$ ..... σ, (ρ)
vapor ..... ρ
density of electric charge, volume ..... ρ
of electric flux $[=d\Psi/dA]$ ..... D

of magnetic flux [$d\Phi/dA$] ..... B
depth or height ..... h, (y)
derivative operator ..... D
derivatives, time ..... Use dots over symbol
deviation ..... δ
deviation angle ..... δ
minimum ..... D, δ_m
deviation, frequency [$=\Delta f/f_r$] ..... δ
deviation, standard (probability) ..... δ
dew-point temperature ..... τ
diameter ..... D
diameter of molecule, collision ..... σ
dielectric coefficient or permittivity or capacitivity ..... ϵ
dielectric coefficient or relative specific inductive capacity ..... ϵ, ϵ_r
dielectric flux density [$\Psi = \int \mathbf{D}\cdot d\mathbf{A}$] ..... $\mathbf{D}$
dielectric flux, total ..... Ψ
difference in optical path ..... Δ
difference of potential. *Cf.* potential
differential operator ..... d
diffraction angle ..... θ
diffusion, coefficient of (fluid) ..... D, (μ)
dioptric power [$=n/f$] ..... D
Dirac h [$=h/2\pi$] ..... $\hbar$
direction cosines ..... l, m, n
discriminant, cubic [$=(b^2/4)+(a^3/27)$] ..... Δ
discriminant, quadratic [$=b^2-4ac$] ..... Δ
disintegration constant [$N = N_0 \exp(-\lambda t)$] ..... λ
dispersion [$=dn/d\lambda$] ..... σ
dispersion, angular [$=d\theta/d\lambda$] ..... D
dispersive power [$=(n_F-n_C)/(n_D-1)$] ..... ω
reciprocal of ..... ν
displacement, angular ..... $\boldsymbol{\theta}$
displacement components (of sound-bearing particle) ..... ξ, η, ζ
displacement constant, first Wien [$=\lambda_m T$] ..... b
second Wien [$=J_m/AT^5$] ..... b_1
displacement current ..... $\dot{\mathbf{D}}$, $\dot{\mathbf{D}}/4\pi$
displacement, electric ..... $\mathbf{D}$
displacement flux density ..... $\mathbf{D}$
displacement flux, total electric [$=\int \mathbf{D}\cdot d\mathbf{A}$] ..... Ψ
displacement, in general ..... s
linear ..... $\mathbf{s}$
longitudinal (acous.) ..... ξ
of sound-bearing particle ..... ξ, η, ζ
transverse (acous.) ..... η, (ξ, y, w)
volume (acous.) X
dissociation, degree of (electrolytes) ..... α
dissociation energy, nuclear ..... Λ
distance:
angular ..... θ
between adjacent principal foci of two lens units ..... Δ
between a principal plane of a lens system and the appropriate principal plane of a unit ..... p
between corresponding points of grating ..... d
between image and corresponding principal plane ..... s'
between image and principal focus of image space ..... x'
between lens units in an optical system ..... d
between object and corresponding principal plane ..... s
from neutral axis to extreme fiber (beams) c
between object and principal focus of object space x
image ..... s'
linear ..... s
object (optics) ..... s
of approach, closest possible (in Rutherford scattering formula) ..... b
radial ..... r
distribution function ..... f, F
divergence operator ..... $\nabla\cdot$
double layer, strength of surface, or surface polarization ..... $\mathbf{P}_s$
dyadic, in general ..... $\boldsymbol{\Phi}$

E

eccentricity of ellipse ..... e
effective, or rms, current I
effective, or rms, potential difference V
efficiency ..... η
current [$=I_{useful}/I_{total}$, electrolysis] ..... η_I
luminous [$=F/P$] ..... K
monochromatic luminous, or luminosity or visibility [$=F_\lambda/\Phi_\lambda$] ..... K_λ
voltage [$=V_{theor}/V_{actual}$, electrolysis] ..... η_V
elastance or reciprocal capacitance ..... S
elasticity, shear modulus of ..... n
volume modulus of ..... k, κ
electric:
charge ..... q, Q
charge density ..... ρ
conductance ..... G, g
conductivity ..... σ, κ, γ
displacement ..... $\mathbf{D}$
displacement, total flux of [$=\int \mathbf{D}\cdot d\mathbf{A}$] ..... Ψ
equivalent of heat ..... J'
field strength ..... $\mathfrak{E}$, $(\mathbf{E})$
flux density [$=\int \mathbf{D}\cdot d\mathbf{A}$] ..... $\mathbf{D}$
flux, total [$=\int \mathbf{D}\cdot d\mathbf{A}$] ..... Ψ
moment of atom, molecule or dipole ..... $\mathbf{p}$
moment, total ..... $\mathbf{p}$
polarization ..... $\mathbf{P}$
polarization, surface ..... $\mathbf{P}_s$
potential V
potential difference. *Cf.* potential
quadrupole moment ..... Q
resistance ..... R, (r)
susceptibility [$\mathbf{P} = \eta\mathfrak{E}$] ..... η
electrochemical equivalent ..... z
electromagnetic scalar potential ..... φ
electromotive force or electromotance or emf ..... E, (V)
electron affinity [$d\varphi = dw/dq$ volts] ..... φ
gross [$d\varphi_g = dw_g/dq$ volts] ..... φ_g
electron emission, total or saturation ..... I_s
electronic charge, modulus of ..... e
electronic mass ..... m
(Use m_s when m is magnetic quantum number.)
ellipse, eccentricity of ..... e
semimajor axis of ..... a
semiminor axis of ..... b
elongation, total, or deflection ..... δ

emissive power, monochromatic ..... J_λ, J_ν
total ..... J
emittance, radiant, or radiant flux density or radiancy or radiance [$=d\Phi/dA = dP/dA$, w/area]. $\mathfrak{R}$, W
end correction for a tube (acous.) ..... α
energy, free:
Helmholtz function [$=U-TS$] ..... A, (F)
Gibbs function [$=H-TS$] ..... G
energy:
internal ..... U, (E)
total (other than work) ..... E, U
density of radiant [$=dU/dV$] ..... u
internal (thermodyn.) ..... U, (E)
intrinsic (thermodyn.) ..... U, (E)
kinetic ..... E_k, (T)
luminous [$=\int F dt$] ..... Q
nuclear dissociation ..... Λ
potential ..... E_p, U, (V)
radiant ..... U
of vibration, total ..... E_v
self [$=mc^2$] ..... ϵ
enthalpy ..... H
enthalpy, free, or Gibbs function ..... G
entropy ..... S
epoch angle ..... ϵ, (φ)
equilibrium constant (products/reactants) ..... K
equivalent conductivity (mho/mole) ..... Λ
equivalents, number of ..... J
error, probable ..... e
excitation potential ..... V_e
expansion, total thermal ..... δ
expansivity, linear, or coefficient of linear expansion .. α, α_l
volume, or coefficient of volume expansion ..... α, α', α_V
exposure [$=Et$] ..... Σ
extinction coefficient or index [$=(l/x)\log_{10} I_0/I$] ..... K

F

factor of safety ..... N
Faraday constant or equivalent ..... F
field strength or intensity, electric ..... $\mathfrak{E}$, $(\mathbf{E})$
magnetic ..... $\mathbf{H}$
figure of merit of reactance [$=X/R$] ..... Q
filament ..... Attach subscript $_f$ to symbol
fine-structure or Sommerfeld constant [$=ch/2\pi e^2$] ..... α
finite increment operators ..... δ, Δ
fluidity (reciprocal of viscosity) ..... φ
flux density, electric ..... $\mathbf{D}$
magnetic ..... $\mathbf{B}$
propagation ..... Ξ
radiant, or radiant emittance or radiance or radiancy [$=d\Phi/dA$ or dP/dA, w/area] ..... $\mathfrak{R}$, W
flux, electric [$=\int \mathbf{D}\cdot d\mathbf{A}$] ..... Ψ
luminous [$=dQ/dt$, lu] ..... F
magnetic [$\int \mathbf{B}\cdot d\mathbf{A}$] ..... Φ
flux or power, radiant [dU/dt] ..... Φ, (P)
focal length of image space ..... f'
of object space ..... f
force ..... $\mathbf{F}$
force constant [$=-F/s$] ..... k
force, gravitational ..... F, F_g
force in a string or membrane ..... F, (T)
force, shearing (in beam section) V
formality ..... F
free energy, Gibbs, or Gibbs function ..... G
free energy, Helmholtz, or Helmholtz function .... A, (F)
free enthalpy, or Gibbs function ..... G
free path ..... l, λ
mean ..... $\bar{l}$, $\bar{\lambda}$
Tait ..... l_T, λ_T
frequency (electric circuits, mechanics, sound) ..... f
frequency (light, quantum theory) ..... ν
frequency, angular [$=2\pi f$] ..... ω
of molecular collision ..... Z
resonant ..... f_r
rotational [rev/time] ..... n
frequency deviation [$=\Delta f/f_r$] ..... δ
friction, coefficient of ..... μ
rolling ..... μ_r
sliding or kinetic ..... μ, (μ_k)
starting or static ..... μ_s
(Use f when μ designates the Poisson ratio)
fugacity ..... f
function ..... f, F, G, H, φ, etc.
function, distribution ..... f, F
fusion, heat of:
per mole L
per unit mass l
per molecule ..... λ
total L
(*Cf.* the last paragraph of the section of this report entitled: "Additional principles and attitudes.")

G

gain of amplifier, power ..... A, A_p
voltage ..... A, A_v
galvanometer deflection ..... δ
gas amplification factor (photoelectric tubes) ..... μ
gas constant [$=pV/nT$] ..... R
molecular, or Boltzmann constant ..... k
gas or vapor, reference to .... Attach subscript $_g$ to symbol
generalized coordinate ..... q
generalized curvilinear coordinates ..... ξ, η, ζ
generalized momentum ..... p
Gibbs function [$=H-TS$] ..... G
partial molal, or chemical potential [$=\partial G/\partial n$] ..... μ
Gibbs function equation, integration constant of I
gradient, electric potential ..... $\mathfrak{E}$, $(\mathbf{E})$
gradient operator ..... ∇
gram-equivalent weight ..... Z
grating lines, total number of ..... N
grating space (distance between corresponding points) ... d
gravitational acceleration. *Cf.* acceleration
gravitational constant, Newtonian ..... G
gravitational force ..... F, F_g
grid, control
Use subscript $_g$ or $_{g1}$, etc., numbered from cathode
injector ... Use subscript $_{g4}$, etc., numbered from cathode
screen
Use subscript $_s$ or $_{g2}$, etc., numbered from cathode
suppressor
Use subscript $_{su}$ or $_{g3}$, etc., numbered from cathode
grid control ratio (thyratrons) ..... μ

grid or input admittance with plate-load $[=g_g-jb_g]$ .. y_g
grid-plate transadmittance $[=g_{gp}-jb_{gp}]$ ..... y_{gp}
real part of, or grid-plate transconductance .. g_{gp}, (g_m)
gyration, radius of ..... k
gyromagnetic ratio ..... g

H

half-angle subtended by point object at objective of microscope ..... α
half-life (radioactivity) ..... T
Hamiltonian function or operator ..... H
perturbing ..... $\mathcal{H}$
Hamilton-Jacobi equation variable, time dependent ..... W, (V)
head (hydrodyn.) ..... h
heat capacity. *Cf.* thermal capacity
heat content or enthalpy ..... H
heat content, relative L
heat entering system ..... q
heat equivalent, electric ..... J, (J')
mechanical, or Joule equivalent ..... J
heater ..... Attach subscript $_h$ to symbol
heat flow path, length of ..... L, l
heat of fusion or vaporization, per mole ..... $\mathbf{L}$
per molecule l
per unit mass l
total L
(*Cf.* the last paragraph of the section of this report entitled: "Additional principles and attitudes.")
heat, quantity of ..... Q
Heaviside time operator $[=\mathrm{d}/\mathrm{d}t]$ ..... p
height ..... h, (y)
Helmholtz function or maximum isothermal work function or Helmholtz free energy $[=U-TS]$ ..... A, (F)
Henry law constant ..... H
Hermitian function ..... H (with suitable subscript)
Hertzian vector ..... $\mathbf{\Pi}$
Hessian function ..... H
humidity, absolute ..... ρ
relative ..... r, f
hydrolysis constant ..... K_h
hydrolysis, degree of ..... h

I

ice-point, ordinary ..... t_0
absolute ..... T_0
illumination or illuminance $[=\mathrm{d}F/\mathrm{d}A]$ ..... E
image distance ..... s'
image size ..... y'
impact parameter (Rutherford scattering formula) ..... p
impedance ..... Z
impedance, specific acoustic $[Z/A]$ ..... z
increment operator, finite ..... δ, Δ
index of refraction. *Cf.* refractive index
indices of Bragg reflection ... $h_1[=nh]$, $h_2[=nk]$, $h_3[=nl]$
indices, Miller ..... h, k, l
inductance L
mutual ..... M, L_{12}, etc.
reciprocal $[=1/L]$ ..... Γ
induction, or partial capacitance, coefficient c
induction density, electric ..... $\mathbf{D}$
magnetic ..... $\mathbf{B}$
induction, electric flux of $[=\int \mathbf{D}\cdot\mathrm{d}\mathbf{A}]$ ..... Ψ
magnetic flux of $[=\int \mathbf{B}\cdot\mathrm{d}\mathbf{A}]$ ..... Φ
inductive reactance ..... X_L
inductivity or absolute permeability ..... μ
inertia of photographic plate i
integration constant of Gibbs function equation I
intensity, acoustic (e.g., erg cm^{-2} sec^{-1}) I
luminous, or candlepower $[=\mathrm{d}F/\mathrm{d}\omega$, lu/steradian$]$ .. I
of magnetization or magnetization ..... $\mathbf{M}$
radiant $[=\mathrm{d}\Phi/\mathrm{d}\omega=\mathrm{d}P/\mathrm{d}\omega]$ ..... J
internal, or intrinsic, energy (thermodyn.) ..... U, (E)
interplanar distance (Bragg law) ..... d
ionization, degree of (electrolytes) ..... α
ionization potential ..... V_i
irradiancy or irradiance $[=\mathrm{d}\Phi/\mathrm{d}A$ or $\mathrm{d}P/\mathrm{d}A$, w $\mathrm{cm}^{-2}]$ $\mathcal{E}$, H

J

Jacobian determinant ..... J
inverse $(jJ=1)$ ..... j
Joule equivalent ..... J
electric ..... J, (J')
Joule-Thomson coefficient $[\partial T/\partial p|_H]$ ..... μ

K

Kelvin temperature ..... T, (Θ)
Kerr constant ..... K
kinetic energy ..... E_k, (T)
average molecular $[=\frac{1}{2}m\bar{v}^2]$ ..... ϵ
kinetic potential or Lagrangian function L
$1/kT$ ..... β

L

Lagrange function or Lagrangian $[=E_k-E_p]$ L
Laguerre function ..... L (with suitable subscript)
Landé factor ..... g
Laplace operator ..... ∇^2
spherical $\left[\frac{1}{\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial}{\partial\theta}\right)+\frac{1}{\sin^2\theta}\frac{\partial^2}{\partial\varphi^2}\right]$ ..... Λ
latitude (colatitude $=\varphi$) ..... λ
leakage coefficient, magnetic ..... σ
Legendre polynomial ..... $P_{l,m}$
associated $[=P_{l,m}(\theta)\exp im\varphi]$ ..... $Y_{l,m}$
length l
of arc or path ..... s
of image ..... y'
of object (optics) ..... y
of prism base ..... t
of vibrating string, rod or tube l
optical, of microscope tube ..... Δ
rest ..... l_0
lens zone, radius of ..... h
light, quantity of, or luminous energy ..... Q
speed in vacuum c
linear:
acceleration ..... $\mathbf{a}$
density $[=m/l]$ ..... λ, (ρ)

displacement ..... **s**
distance ..... *s*
expansivity or linear coefficient of expansion .... α, (λ)
velocity ..... **u**, **v**
lines of grating, total number of ..... *N*
liquid, reference to ..... Attach subscript $_l$ to symbol
load per unit displacement ..... *k*
longitude ..... φ
Lorentz unit [$=Be/4\pi mc^2$] ..... *L*
Loschmidt number (no./cm³ at 0°C and 1 A_e) ..... n_0
luminance or brightness ..... *B*
luminosity or visibility factor ..... K_λ
luminous:
efficiency [$=F/P=F/\Phi$] ..... *K*
efficiency, monochromatic, or visibility factor ..... K_λ
energy [$=\int F dt$] ..... *Q*
flux [$=dQ/dt$] ..... *F*
intensity or candlepower [$=dF/d\omega$] ..... *I*
intensity, initial ..... I_0

M

magnetic:
field strength or intensity ..... **H**
flux [$=\int \mathbf{B}\cdot d\mathbf{A}$] ..... Φ
flux density or induction ..... **B**
leakage coefficient ..... σ
moment ..... **m**
moment of atom, dipole or molecule ..... **m**
permeability ..... μ
polarization or magnetization ..... **M**
poles, number of pairs (elec. mach.) ..... *p*
pole strength ..... *p*, (*m*)
potential, scalar ..... $\mathcal{F}$
potential, vector ..... **A**
rotation, specific, or Verdet constant ..... *V*, ω
shell strength ..... *I*
susceptibility ..... *k*
susceptibility, specific [$=k/\rho$] ..... χ
magnetization ..... **M**
specific [$=\mathbf{M}/\rho$] ..... $\boldsymbol{\sigma}$
magnetomotive force or magnetic scalar potential ..... $\mathcal{F}$
magneton, orbital or Bohr ..... μ_0
magneton, nuclear [$=\mu_0/1838$] ..... μ_I
magnification ..... *m*
magnification, angular [$=\tan u'/\tan u$] ..... γ
mass, longitudinal [$=m_0/(1-\beta^2)^{\frac{1}{2}}$] ..... m_l
of electron (use m_e when *m* is magnetic quantum number) ..... *m*
of molecule ..... *m*
per mole ..... *M*
per unit area ..... σ, (ρ)
per unit length ..... λ, (ρ)
reduced [$1/\mu=(1/m_1)+(1/m_2)$] ..... μ
rest ..... m_0
total ..... *M*
transverse [$=m_0/(1-\beta^2)^{\frac{1}{2}}$] ..... m_t
maximum ..... Attach subscript $_m$ or $_{max}$ to symbol
mean free path ..... l, $\bar{\lambda}$
mean-life (radioactivity) ..... τ
mechanical equivalent of heat or Joule equivalent ..... *J*
Miller indices ..... *h*, *k*, *l*
minimum ..... Attach subscript $_{min}$ to symbol
mixing ratio or water-vapor content ..... *w*
modulation factor ..... *m*
modulus of decay [$s=A\cos(\omega t+\varphi)\exp(-t/\tau)$] ..... τ
modulus of elasticity, shear ..... *n*
volume ..... *k*, κ
Young ..... *E*, *Y*
modulus of section [$=I/c$, where *c* is distance of neutral axis from extreme fiber) ..... *Z*
molecular:
collision frequency ..... *Z*
concentration or density [=no./cm³] ..... *n*
conductivity ..... μ
cross section, effective ..... σ, *S*
density at 0°C and 1A_e, or Loschmidt number ..... n_0
diameter (collision) ..... σ
gas constant or Boltzmann constant) ..... *k*
kinetic energy, average [$=\frac{1}{2}m\bar{v}^2$] ..... ϵ
mass ..... *m*
volume ..... *V*
weight ..... *M*, $\tilde{M}$
weight, ionic (if necessary to distinguish between ions and neutrals) ..... M_i, $\tilde{M}_i$
molecules, number of ..... *N*
mole factor or van't Hoff coefficient ..... *i*
moles, number of ..... *n*
moment, electric (total) ..... **p**
electric, of atom or dipole or molecule ..... **p**
magnetic (total) ..... **m**
magnetic, of atom or dipole or molecule ..... **m**
of area [$=\int y dA$] ..... *Q*
of inertia ..... *I*, I_{xx}, etc., (*J*)
moment of inertia, areal
polar [$=\int r^2 dA$] ..... *J*
rectangular [$=\int y^2 dA$] ..... *I*
momentum, generalized ..... **p**
mutual conductance. *Cf.* transconductance
mutual inductance ..... *M*, L_{12}, etc.

N

Naperian base ..... exp, ϵ, *e*
natural or resonant frequency ..... f_r
normality ..... *C*
normalization factor (probability) ..... *N*
nuclear dissociation energy ..... Λ
nuclear magneton [$=\mu_0/1838$] ..... μ_I
nuclear radius ..... *r*
number ..... *n*
number of atoms or nuclei (if more than one type is considered) ..... $N_{1,2...}$
number of atoms or nuclei, at time *t* (radioactivity) ..... *N*
initial (radioactivity) ..... N_0
initial (if more than one type is considered) .... $N^0_{1,2...}$
number:
of components (Gibbs phase rule) ..... *n*
of equivalents ..... *J*
of lines of a grating, total ..... *N*
of molecular collisions per unit time or collision frequency ..... *Z*

of molecules ..... N
of molecules per cubic centimeter (0°C, 1A$_a$) or Loschmidt number ..... n_0
of molecules per gram-molecule (0°C, 1A$_a$) or Avogadro number ..... N, N_0
of molecules per unit volume or molecular concentration ..... n
of moles ..... n
of pairs of poles (elec. mach.) ..... p
of phases (elec. circuits) ..... m
of revolutions or rotations per unit time ..... n
of turns or of conductors ..... N

O

object distance (optics) ..... s
object length (optics) ..... y
opacity (reciprocal of absorptance) ..... O
optical attenuation ..... D
optical density [$=\log_{10} I_0/I$] ..... D
optical length of microscope tube ..... Δ
optical path difference ..... Δ
optical transmittance or transmission factor [$=F_t/F_i$] ..... τ
orbital or Bohr magneton ..... μ_0
order of spectrum ..... m, (n)
oscillation period ..... T
osmotic pressure ..... p, Π, (π)

P

path difference, optical ..... Δ
peak current ..... $\hat{I}$, (I_{pk})
peak potential ..... $\hat{V}$, (V_{pk})
Peltier coefficient ..... Π
Peltier potential ..... V_π
periodicity ..... ω
resonant ..... ω_r
period of a periodic motion ..... T
permeability or inductivity, magnetic ..... μ
permeability, reciprocal, or reluctivity ..... ν
permeability, relative magnetic ..... μ, μ_r
permeance [$=L/N^2$] ..... Λ
permittance or capacitance C
permittivity or dielectric coefficient ..... ϵ
phase angle ..... φ
phase constant [$\gamma=\alpha+j\beta$] ..... β
photoelectric threshold frequency ..... ν_0, (f_0)
photoelectric tube, sensitivity of, static ..... S
dynamic ..... s
2870 tungsten ..... S_{2870}, s_{2870}
photographic plate, inertia of i
piezoelectric strain constant or modulus ..... δ
piezoelectric stress constant ..... ϵ
Planck constant ..... h
Planck function [$=-A/T$] ..... Ψ
Planck radiation law constants [$J_\lambda=Ac_1\lambda^{-5}/(\exp c_2/\lambda T-1)$] ..... c_1, c_2
plane spacing in a crystal, Bragg ..... d
plate ..... Attach subscript $_p$ to symbol
plate power ..... P_p
plate resistance ..... r_p
Poisson ratio ..... σ
polar coordinates ..... r, θ
polarization, electric ..... $\mathbf{P}$
magnetic, or magnetization ..... $\mathbf{M}$
surface, or strength of double layer (elec.) ..... $\mathbf{P}_s$
pole strength, magnetic ..... p, (m)
position vector ..... $\mathbf{r}$
potential, chemical ..... μ
potential coefficient, partial ..... p
potential difference:
average ..... $\bar{V}$, V_{av}
contact or Volta ..... V_v
excitation ..... V_e
instantaneous v
maximum ..... V_m, (V_{max})
maximum peak ..... $\hat{V}_m$
peak ..... $\hat{V}$, (V_{pk})
Peltier ..... V_π
quiescent ..... V_Q
rms or effective V
Seebeck ..... V_s
Thomson ..... V_t
steady d.c. V
potential:
electric V
electromagnetic scalar ..... φ
energy ..... E_p, U, (V)
gradient, electric ..... $\mathfrak{E}$, $(\mathbf{E})$
inner (metals) ..... V, V_i
ionization ..... V_i
kinetic, or Lagrange function L
magnetic scalar ..... $\mathfrak{F}$
magnetic vector ..... $\mathbf{A}$
velocity (hydrodyn.) ..... φ
potentials, retarded .....
Symbols same as for unretarded potentials. In defining equation place the space-independent part of the integrand in square brackets
power ..... P
(Use same system of subscripts as for potential difference except that P unmodified signifies average power.)
power, active (elec.) ..... P
input ..... P_i
of lens system or refracting power [$=n/f$ diopters] .. D
output ..... P_0
plate ..... P_p
radiant, or radiant flux ..... P, Φ
thermoelectric ..... Q
Poynting vector ..... $\mathbf{\Pi}$
pressure ..... p
(Use π for total pressure when p represents vapor pressure.)
pressure (acous.):
amplitude of simple harmonic ..... P
static ..... P_0
varying ..... p
pressure coefficient ..... β
pressure, critical ..... p_c
osmotic ..... p, Π, (π)
partial ..... p
vapor ..... p

probability ..... P
probable error ..... e
product operator, continued ..... Π
product of inertia ..... I_{xy}, etc.
propagation constant $[=\alpha+j\beta]$ ..... γ
propagation flux density ..... Ξ
pulsatance or periodicity ..... ω

Q

Q-factor, or quality factor, of reactor $[=X/R]$ ..... Q
quadratic coefficients $[ax^2+bx+c=0]$ ..... a, b, c
quadratic discriminant $[=b^2-4ac]$ ..... Δ
quadrupole moment, electric ..... Q
quantity, of electric charge ..... q, Q
  of heat ..... Q
  of light or luminous energy ..... Q
quantum number:
  azimuthal or orbital l
  azimuthal or orbital, total L
  hyperfine $[=I+J]$ ..... F
  inner ..... j
  inner, total ..... J
  magnetic ..... m
  magnetic, total ..... M
  principal ..... n
  rotational ..... R
  spin ..... s
  spin, total ..... S
  vibrational v
  (Strictly speaking, spin is not a quantum number.)

R

radial distance ..... r
radiancy, or radiant emittance, or radiance, or radiant flux density $[=\mathrm{d}\Phi/\mathrm{d}A=\mathrm{d}P/\mathrm{d}A]$ ..... $\mathfrak{R}, W$
radiant energy ..... U
  density of $[=\mathrm{d}U/\mathrm{d}V]$ ..... u
radiant intensity $[=\mathrm{d}\Phi/\mathrm{d}\omega=\mathrm{d}P/\mathrm{d}\omega]$ ..... J
  spectral $[=\mathrm{d}J/\mathrm{d}\lambda]$ ..... J_λ
radiant power or flux $[=\mathrm{d}U/\mathrm{d}t]$ ..... P, Φ
radiation constants. *Cf.* Planck radiation law constants
radius ..... r
  Bohr $[=h^2/4\pi^2me^2]$ ..... a_1
  of circle of least confusion ..... Z
  of curvature ..... ρ
  of gyration ..... k
  of image of a point ..... Z
  of lens zone ..... h
  of nucleus ..... r
  of tube, disk or membrane (acous.) ..... a, (R)
radius vector ..... $\mathbf{r}$
range (radioactivity) ..... R
ratio of speed to speed of light $[=v/c]$ ..... β
reactance X
  capacitive ..... X_C
  inductive ..... X_L
  specific acoustic $[X/A]$ x
reaction rate, specific, or reaction velocity constant ..... k
reaction velocity $[=-\mathrm{d}c/\mathrm{d}t]$ ..... u
reciprocal capacitance or elastance ..... S
reciprocal impedance or admittance ..... Y
reciprocal inductance ..... Π
reciprocal of dispersive power ..... ν
reciprocal permeability or reluctivity ..... ν
reciprocal reactance or susceptance ..... B, b
reciprocal resistance or conductance ..... G, g
recombination, coefficient of ..... α
rectangular coordinates ..... x, y, z
reduced properties ..... Attach subscript $_r$ to symbol
reflectance or reflectivity or reflection factor $[=F_r/F_i]$ ... ρ
refracting power or power of a lens system $[=n/f]$ .... D
refractive index ..... n, (μ)
  group ..... n_g, (μ_g)
relative dielectric coefficient or specific inductive capacity ..... ϵ, ϵ_r
relative magnetic permeability ..... μ, μ_r
relativity ratio $[=v/c]$ ..... β
reluctance ..... $\mathfrak{R}$
reluctivity $[=1/\mu]$ ..... ν
residual of an observation ..... r
resilience, coefficient of, or coefficient of restitution ..... e
resistance, acoustic ..... R
  electric ..... R, (r)
  plate ..... r_p
  radiation ..... R
  specific, or resistivity ..... ρ
  specific acoustic $[R/A]$ ..... r
  thermal ..... R
  thermal coefficient of ..... α
resistivity or specific resistance ..... ρ
resistivity, thermal ..... $1/k$
resolving power of telescope, angular ..... α
resonant frequency ..... f_r
resonant periodicity ..... ω_r
restitution, coefficient of, or resilience ..... e
restoring force per unit displacement ..... k
retarded potentials. *Cf.* potential
reverberation time ..... T
revolution or rotations per unit time ..... n
Richardson equation factors $[I_s=AT^2\exp(-b/T)]$ .. A, b
rigidity or shear modulus of elasticity ..... n
rotational frequency [rev/time] ..... n
rotation, angle of optical ..... θ
  specific $[=\theta/lc]$ ..... α
  specific magnetic, or Verdet constant ..... V, ω
Rydberg constant ..... R
  at infinite mass ..... R_∞

S

safety factor ..... N
sag or deflection of beam ..... δ
self-energy $[=mc^2]$ ..... ϵ
sensitivity of photoelectric tube:
  static ..... S
  dynamic ..... s
  2870 tungsten ..... S_{2870}, s_{2870}
shearing force in beam section V
shear modulus of elasticity ..... n
shell, strength of magnetic I

slip ..... s
slit width (transparent portion) ..... a
solid, reference to ..... Attach subscript $_s$ to symbol
Sommerfeld or fine-structure constant $[=ch/2\pi e^2]$ ..... α
sound. *Cf.* acoustic
spacing of Bragg planes in a crystal ..... d
specific heat or thermal capacity c
  for constant pressure ..... c_p
  for constant volume ..... c_V
  ratio of $[=c_p/c_V]$ ..... γ
specific inductive capacity or relative dielectric coefficient ..... ϵ, ϵ_r
specific magnetic rotation or Verdet constant ..... V, ω
specific resistance or resistivity ..... ρ
specific volume v
specific weight $[w/V]$ ..... γ
speed ..... u, v
  at time t ..... u, u_t, v, v_t
  angular ..... ω
  average ..... $\bar{u}$, $\bar{v}$, u_{av}, v_{av}
  initial ..... u_0, v_0
  linear or particle ..... u, v
  most probable ..... $\hat{u}$, $\hat{v}$, $(\hat{c}_0)$
  of light in vacuum c
  of sound or other wave ..... c, v
  rms ..... $\overline{\overline{u}}$, $\overline{\overline{v}}$, (C)
spherical function or associated Legendre polynomial. $Y_{l,m}$
spin ..... s
  nuclear I
  total ..... S
spring constant $[=-F/s]$ ..... k
standard deviation (probability) ..... δ
statistical weight or degeneracy ..... g
Stefan-Boltzmann constant $[=J/T^4]$ ..... σ
steradiancy or steradiance $[=\mathrm{d}W/\mathrm{d}\omega]$ ..... $\mathfrak{B}$
strength of magnetic pole ..... p, (m)
strength of magnetic shell I
summation operator ..... Σ
super-compressibility factor ..... y
surface tension, coefficient of ..... γ, σ
susceptance or reciprocal of reactance ..... B, b
susceptibility, electric $[\mathbf{P}=\eta\mathfrak{E}]$ ..... η
  specific magnetic $[=k/\rho]$ ..... χ
  volume magnetic $[\mathbf{M}=k\mathbf{H}]$ ..... k

T

Tait free path ..... l_T, λ_T
temperature, absolute ..... T, (Θ)
  coefficient of resistance ..... α
  critical ..... t_c, T_c
  dew-point ..... τ
  of ice-point, absolute ..... T_0
  of ice-point, ordinary ..... t_0
  ordinary ..... t, (θ)
thermal capacity c
  for constant pressure ..... c_p
  for constant volume ..... c_V
thermal capacity, molar C
  for constant pressure ..... C_p
  for constant volume ..... C_V
thermal:
  conductance ..... $1/R$
  conductivity ..... k
  expansion, linear coefficient of, or linear expansivity ..... α, α_l
  expansion, volume coefficient of, or volume expansivity ..... α, α', α_V
  expansion, total ..... δ
  resistance ..... R
  resistivity ..... $1/k$
thermoelectric power ..... Q
thickness or height ..... h
Thomson coefficient ..... σ
time ..... (Use τ when t is used for temperature.) t, (τ).
time constant ..... τ
time-dependent variable in Hamilton-Jacobi equation ..... W, (V)
time-dependent wave function ..... ψ
time derivatives ..... Use dots over symbol
time-independent wave function ..... u
time operator, Heaviside $[=\mathrm{d}/\mathrm{d}t]$ ..... p
time, reverberation ..... T
torque per unit twist or torsion constant ..... k
transadmittance, grid-plate $[=g_{gp}-\mathrm{j}b_{gp}]$ ..... y_{gp}
transconductance, grid-plate (real part of grid-plate transadmittance) ..... g_{gp}, (g_m)
  at zero frequency and constant plate potential $[=(\partial i_p/\partial v_g)_{v_p}]$ ..... s_p
transition between polymorphic forms ..... Attach subscript $_t$ to symbol
transmission coefficient $[t^x=I_x/I_0=\exp(-ax)]$ ..... t
transmission factor or transmittance, optical ..... τ

U

u/c ..... β
unit vector. *Cf.* vector

V

valence ..... z
van der Waals constants ..... a, b
van't Hoff coefficient i
vapor density ..... ρ
vaporization, heat of:
  per mole L
  per unit mass l
  per molecule l
  total L
  (*Cf.* the last paragraph of the section of this report entitled: "Additional principles and attitudes.")
vapor or gas, reference to ... Attach subscript $_g$ to symbol
vapor pressure ..... p
vapor pressure constant i
variable ..... x, y, z
variable in Hamilton-Jacobi equation, time-dependent ..... W, (V)
variation operator ..... δ
vector, unit, in X-direction i
  in Y-direction ..... j
  in Z-direction ..... k
  tangent to path ..... τ

vector, position ..... $\mathbf{r}$
velocity ..... $\mathbf{u}, \mathbf{v}$
  angular ..... $\boldsymbol{\omega}$
  at time t ..... $\mathbf{u}, \mathbf{v}, \mathbf{u}_t, \mathbf{v}_t$
  average ..... $\bar{\mathbf{u}}, \bar{\mathbf{v}}, \mathbf{u}_{av}, \mathbf{v}_{av}$
  components of linear or particle ... $u_{x,y,z}, v_{x,y,z}, (\mathbf{u}, \mathbf{v}, \mathbf{w})$
  constant, reaction ..... k
  group ..... $\mathbf{u}, \mathbf{v}, \mathbf{u}_g, \mathbf{v}_g$
  initial ..... $\mathbf{u}_0, \mathbf{v}_0$
  ionic ..... $\mathbf{u}$ (with suitable subscript)
  linear or particle ..... $\mathbf{u}, \mathbf{v}$
  most probable ..... $\hat{\mathbf{u}}, \hat{\mathbf{v}}, (\hat{\mathbf{c}}_0)$
  of light in vacuum c
  of sound or other waves ..... c, v
  phase or wave ..... $\mathbf{u}_w, \mathbf{u}_\varphi, (\mathbf{w})$
  potential ..... φ
  reaction $[=-dc/dt]$ ..... u
  rectangular components ..... $\mathbf{u}_{x,y,z}, \mathbf{v}_{x,y,z}$
  root-mean-square ..... $\bar{\mathbf{u}}, \bar{\mathbf{v}}, (\mathbf{C})$
  specific reaction, or reaction velocity constant ..... k
Verdet constant ..... V, ω
viscosity coefficient, kinematic $[=\eta/\rho]$ ..... ν
viscosity, coefficient of ..... η
  coefficient of relative (referred to water) ..... Z
visibility factor or luminosity or monochromatic luminous efficiency $[=F_\lambda/P_\lambda=F_\lambda/\Phi_\lambda \text{ lu w}^{-1}]$ ..... K_λ
voltage. *Cf.* potential difference
voltage efficiency $[=V_{\text{theor}}/V_{\text{actual}}$, electrolysis$]$ ..... η_V
Volta potential or contact potential ..... V_v
volume ..... $V, (\tau)$
  atomic V
  charge density ..... ρ
  critical ..... V_c
  density ..... ρ
  displacement (acous.) X
  expansivity or coefficient of expansion ..... $\alpha, \alpha', \alpha_V$
  modulus of elasticity ..... k, κ
  molecular V
  of a cavity or room V
  of configuration-space V
  of phase space ..... Ω
  specific $[V/m]$ v
  susceptibility, magnetic $[\mathbf{M}=k\mathbf{H}]$ ..... k

W

water-vapor content or mixing ratio ..... w
wave function, time dependent ..... ψ
  time independent ..... u
wave-length ..... λ
wave-length constant $[=2\pi/\lambda]$ ..... k
wave number ..... σ
weight ..... $w, (F, W)$
weightivity or specific weight $[w/V]$ ..... γ
weight, statistical, or degeneracy ..... g
width or breadth ..... b
width of slit (transparent portion) ..... a
Wien displacement conscants:
  first $[=\lambda_m T]$ ..... b
  second $[J_m/AT^5]$ ..... b_1
work ..... $W, (w)$
work function, gross ..... w_g
  maximum isothermal, or Helmholtz function ... $A, (F)$
  net ..... w
  per unit charge, gross, or gross electron affinity $[d\varphi_g=dw_g/dq$, volts$]$ ..... φ_g
  per unit charge, net, or electron affinity $[d\varphi=dw/dq$, volts$]$ ..... φ

Y

Young modulus of elasticity ..... E, Y

Z

zone of lens, radius of ..... h

Supplementary List of Symbols

There are various terms for which there seems to be as yet no unanimity in the symbols employed and for which the committee is making no recommendations. These include such quantities as:

angle of inclination of ray with respect to axis in image space
angle of inclination of ray with respect to axis in object space
acoustic capacitance, compliance, mass, resistance, radiation resistance and characteristic impedance
amplitude of harmonic velocity
angles of incidence and refraction
attenuation coefficient (for displacement in plane waves)
attenuation coefficient (for energy of waves)
current density (elec.)
dilatation (acous.)
dissipation function (acous.)
elasticity (various quantities in)
emissivity
energy density, sound
energy flux, sound
energy reflection coefficient (acous.)
energy transmission coefficient (for a wall or panel)
impulse (both linear and angular)
intensity level (acous.)
loudness
luminous density
luminous emittance
magnification
mechanical impedance, reactance and resistance
mobility constant, ionic
mobility, ionic
moment
momentum (both linear and angular)
power, apparent and reactive
specific gravity
tension
torque
volume current (acous.)

It will be interesting to discuss briefly one of these for the illustration it affords of the problems faced in the choice of a set of symbols.

Momentum is variously represented by **H**, **L**, **M** and **p**. The committee finds proponents for each of these. Some commentators believe that the same symbol, possibly with differentiating subscripts, should designate both linear momentum and angular momentum; others recommend the use of dissimilar letters. One of the factors contributing to this divergence of opinion is that momentum, while essentially an elementary concept, occurs in contexts of varying abstractness. In advanced mechanics, **p** and q are the common, almost the standard, symbols for momentum (both linear and angular) and for the generalized coordinates, respectively. The helpfulness, in elementary textbooks, of a symbol closely correlated with the name of the magnitude is advanced as an argument for adopting

M; but this letter is also the initial letter of mass, a quantity that occurs with momentum. Persons favoring **L** refer to its complete acceptance in atomic physics for orbital angular momentum, although they admit that it is the symbol for only one of the angular momentums. The use of h and $\hbar$ for the natural packet of angular momentum calls to mind **H** for angular momentum in general.

These considerations are typical of those which the committee has faced for each of the controversial symbols. Physics no longer has only five divisions but rather is part of a continuum of knowledge punctuated by many diffuse boundary regions and a few tenuous, but not completely empty, regions. Where the pressure for standardization in the boundary layer between two fields of physics is marked, we have frequently made a recommendation favoring the coordination of the two fields. Where the boundary region between two fields of physics or between physics and another science is not yet exploited, we have either voted a compromise or "agreed to disagree." In the latter case, the concept has been placed in the foregoing Supplementary List. The committee has attempted to function principally as a melting pot among established usage factions.

Acknowledgments

Many individuals have made recommendations on specific items and matters of policy. To all of these, and especially to those who have traced details persistently to a satisfactory conclusion, thanks are due. In addition to the acknowledgments previously published,[9] the committee wishes to record its gratitude to:

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The Committee on Letter Symbols and Abbreviations of the American Association of Physics Teachers.—E. L. CHAFFEE, Harvard University; A. W. FOSTER, University of Western Ontario; GRANT O. GALE, Grinnell College; A. T. JONES, Smith College; VICTOR F. LENZEN, University of California; MADELINE M. MITCHELL, American Institute of Physics; DUANE ROLLER, Hunter College; HAROLD KENNETH HUGHES, University OF NEWARK, *Chairman*.

[9] Am. J. Phys. (Am. Phys. T.) **6**, 217 (1938).

THE view that the sole function of science is the discovery and study of natural facts and principles without regard to the social implications of the knowledge gained, can no longer be maintained. It is being widely recognized that science cannot be divorced from ethics, or rightly absolve itself from the human responsibilities of the application of its discoveries to destructive purposes of war or economic disturbances in times of peace. Men of science can no longer stand aside from the social and political questions involved in the structure which has been built up from the materials provided by them, and which their discoveries may be used to destroy. It is their duty to assist in the establishment of a rational harmonious social order out of the welter of human conflict into which the world has been thrown through the prostitution of the rich gifts with which they have endowed the human race. Science has made the world one through the facilities of transport and communication now available; and it recognizes no political or racial boundaries in the fields of knowledge. By the wise use of this knowledge, the earth could indeed become a celestial dwelling-place instead of a world of dust and ashes which prevailing conditions seem to be making its destiny.—Sir Richard Gregory, "Cultural contacts of science," *Nature* **142**, 1061 (1938).

Reproductions of Prints, Drawings and Paintings of Interest in the History of Physics

13. Lectures at the Surrey Institution as Portrayed by Thomas Rowlandson

E. C. WATSON
California Institute of Technology, Pasadena, California

THE success of the Royal Institution (see Reproduction 11 in this series), together with the rapid growth of London south of the Thames, led in 1808 to the establishment of a similar project on Blackfriars Road just south of Blackfriars Bridge. The purpose of *The Surrey Institution*, as it was called, was the same as that of the Royal Institution and the building which housed it contained likewise a library and reading rooms, a chemical laboratory, conversation rooms and a spacious anteroom for the display of scientific apparatus, in addition to an elaborate lecture room. This theater, which seated approximately 500 people, was considered one of the finest rooms in London. FRIEDRICH CHRISTIAN (FREDRICK) ACCUM[1] (1769–1838), best remembered as a pioneer in the field of gas lighting, but also known as a dealer in scientific supplies, a scientific investigator, a pure-food agitator and an industrial expert, was professor of chemistry and mineralogy; and his lectures, which were begun in November, 1808, were well attended. The project was not long successful, however, and by 1823 it was abandoned.

[1] For an interesting account of his life and accomplishments see C. A. Browne, "The life and chemical services of Fredrick Accum," J. Chem. Ed. **2**, 829, 1008, 1140 (1925). Brief notes regarding him will be found also in Nature **141**, 1153 (1938) and in the *Dictionary of National Biography*.

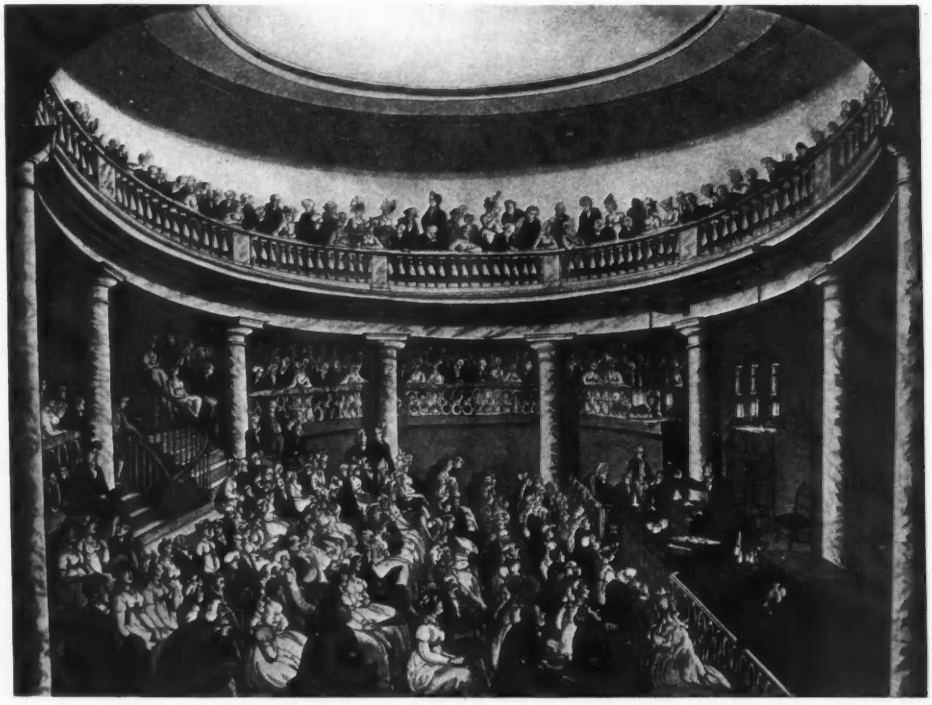

PLATE 1. FREDRICK ACCUM LECTURING AT THE SURREY INSTITUTION IN LONDON.

PLATE 2. A caricature by Thomas Rowlandson of Fredrick Accum lecturing at the Surrey Institution.

The first plate gives a very adequate idea of the lecture theater with its two galleries, the uppermost supported by eight Doric columns of Derbyshire marble. It is reproduced from one of the 104 magnificent aquatints, depicting every phase of the colorful life in London under the Regency, which appeared in that most distinguished of color-plate books, *The microcosm of London; or London in miniature*, published by RUDOLPH ACKERMANN in 1808–1810. The drawings themselves are the work of AUGUSTUS CHARLES PUGIN (1762–1834), one of the best archiectural draftsmen of the period, and THOMAS ROWLANDSON (1756–1827), the caricaturist who portrayed "the high and low life of his time with incomparable gusto and charm."

The second plate is a caricature of the same scene, also by ROWLANDSON. A fair likeness of ACCUM is provided, but the other figures have not been identified, if indeed they were intended to represent actual persons. "Wonder and interest are expressed by the faces of the stylishly dressed audience" and "one old enthusiast, who watches the lecture with his head and hands resting upon a cane, has a book marked 'Accum's Lectures' thrust in his side-pocket." This is probably typical of the interest which London society took in such lectures. The original print, which is quite rare, is 13×9 in. in size and brightly colored.

THE imaginary number is a fine and wonderful recourse of the divine spirit, almost an amphibian between being and not being.—LEIBNIZ.

A Brief Table of Meter-Kilogram-Second Units

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The following table is designed to aid the physics teacher in his first use of mks units. For brevity, we have omitted many quantities about which there should be no question. Defining equations are given in a simple rather than a more general form. In the cgs equivalents the value used for the speed of light is 3×10^{10} cm/sec rather than the more exact value 2.99776×10^{10} cm/sec. The factor 4π is left in the equivalents for clarity and also because in many calculations it may be canceled. The rationalized system is used. For more complete definitions and discussion see "A Report of the A. A. P. T. Committee on Electric and Magnetic Units."[1]

SYMBOL	QUANTITY	DEFINITION	UNIT	EQUIVALENTS
l	length		meter	100 cm
m	mass		kilogram	1000 gm
F	force	$F=ma$	newton	10^5 dynes
W	work	$W=\int F\cos\theta\,dl$	joule	10^7 ergs
P	power	$P=dW/dt$	watt	10^7 erg/sec
T	torque	$T=Fl\sin\theta$	newton·meter	10^7 dyne cm
i	electric current	[2]	ampere	0.1 emu or 3×10^9 esu
q	electric charge	$q=\int i\,dt$	coulomb	0.1 emu or 3×10^9 esu
V	potential difference	$V=W/q$ or $V=P/i$	volt	10^8 emu or 1/300 esu
R	resistance	$R=V/i$	ohm	10^9 emu or $1/(9\times10^{11})$ esu
E	electric field strength	$E=F/q$ or $E=-dV/dr$	newton/coulomb *or* volt/meter	10^6 emu or $1/(3\times10^4)$ esu
C	capacitance	$C=q/V$	farad	9×10^{11} esu
ϵ	capacitivity or dielectric constant	$F=qq'/4\pi\epsilon r^2$ or $C=\epsilon S/d$	farad/meter	$4\pi9\times10^9$ esu $\epsilon_0=1/(4\pi8.98656\times10^9)$ *f/m*
κ	relative capacitivity	$\kappa=\epsilon/\epsilon_0$		For free space $\kappa=1$
L	inductance	$Ldi/dt=-V$	henry	10^9 emu
$\mathfrak{F}$	magnetomotive force	$\mathfrak{F}=Ni$	ampere·turn	0.4π gilberts
H	magnetic field strength	$H=\int i\sin\theta\,dl/4\pi r^2$ (or $H=Ni/l$ for long solenoid)	ampere·turn/meter *or* ampere/meter *or* newton/weber	$4\pi/10^3$ oersted
M	magnetic moment	$MH\sin\theta=T$	weber·meter	$10^{10}/4\pi$ emu
p	pole strength	$p=M/l$	weber	$10^8/4\pi$ emu
ϕ	magnetic flux	$V=-N\,d\phi/dt$	weber	10^8 maxwells
$\mathfrak{R}$	reluctance	$\mathfrak{R}=\mathfrak{F}/\phi$	rowland	$4\pi/10^9$ emu (oersted)
B	magnetic induction or flux density	$B=\phi/S$ or $dF=Bi\sin\theta\,dl$	weber/meter^2	10^4 gauss
μ	permeability	$\mu=B/H$	weber/ampere·meter	$10^7/4\pi$ emu $\mu_0=4\pi/10^7$ *weber/amp·m*
μ_r	relative permeability	$\mu_r=\mu/\mu_0$		For free space $\mu_r=1$
I	intensity of magnetization	$I=M/V=p/S$ $(B=\mu_0H+I)$	weber/meter^2	$10^4/4\pi$ emu
D	electric displacement	$D=\epsilon E$	coulomb/meter^2	$12\pi\times10^5$ esu
P	electric polarization	$P=q/S$ $(D=\epsilon_0E+P)$	coulomb/meter^2	3×10^5 esu

[1] Am. J. Phys. (Am. Phys. T.) 6, 144 (1938).
[2] To define the ampere it may be said that two infinite parallel wires 1 m apart carrying currents of 1 amp in opposite directions repel one another with a force of 2×10^{-7} newton per meter of length.

NOTES AND DISCUSSION

Device for Illustrating the Production of Laue Spots

THE simple device pictured in Fig. 1 has been used, both in lectures and in private study, to illustrate the production of Laue spots. Ordinary light takes the place of x-rays, a small mirror of adjustable orientation represents the reflecting crystal planes and the spots are recorded by penciling the successive locations at which the reflected light beam strikes a sheet of drawing paper. Since the apparatus has been used for illustration rather than analysis, we have confined its application to the single case of a cubic crystal illuminated by a beam lying parallel to one of the crystal axes. Other cases could be readily substituted.

As shown in Fig. 1, the small mirror is held in a fixed location but can be placed in various orientations by the rubber bands attached to its plywood backing plate and looped over selected screw hooks in the plane of the spot pattern. These hooks are placed at equal intervals along the horizontal and vertical axes of this plane, and represent on a magnified scale the occupied lattice points of the crystal. The mirror is stuck onto a small block of wood that obtains its support from the tension of the rubber bands and a short length of chain (concealed by the mirror) which tethers it to a vertical screw hook. The two axes in the plane of the spot pattern, together with the third one containing the mirror, form a rectangular coordinate system paralleling the supposed crystallographic axes of the crystal whose Laue spot pattern is to be simulated. With the mirror located at a distance of five units (10 in. in the model shown) from the origin, it is possible to give the mirror some 40 different orientations, all inclined to represent correctly crystal planes with small indices. Since the reflected x-ray beam, in case it exists, is directed in conformity with the ordinary law of reflection, the reflected light spots of the model must distribute themselves so as to simulate one quadrant of the Laue spot pattern of a cubic crystal.

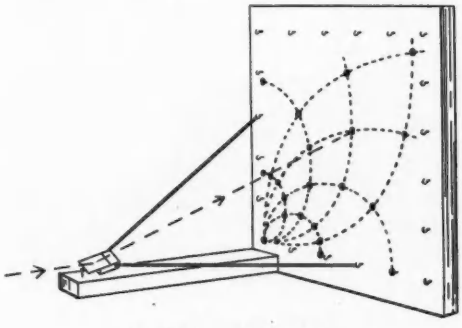

FIG. 1. Diagram of the device.

To render the spot positions definite, the beam incident upon the mirror is rendered convergent by a lens so located as to bring the reflected beam approximately to focus upon the paper. The spot pattern which one quickly traces with this device is a correct representation of the actual Laue pattern. The reasons for the symmetries of Laue spot distributions become evident to the student, and their location upon intersecting elliptical loci is readily comprehended.

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Three-Dimensional Representation of X-Ray Absorption Coefficients

IN an abstract[1] of a report presented at the Stanford meeting of the American Association of Physics Teachers, we described a model representing x-ray mass-absorption coefficients as functions of x-ray wave-length and absorber atomic number. This model is illustrated by Figs. 1 and 2. In Fig. 1 the origin is at the corner in the foreground with the wave-length axis receding to the right and the atomic-number axis with its 92 separate sheets Presdwood extending to the left. Vertical heights represenof total mass-absorption coefficients derived from compret hensive empirical formulas and numerical values kindly-supplied by Dr. S. J. M. Allen. The wave-length range represented is from zero to 4A, the scale being 1A = 10 in.

In Fig. 2 the observer is looking in the negative direction of the wave-length axis with atomic numbers increasing toward his right. Unfortunately, the spacing blocks in serted between the boards and possessing no physica

FIG. 1. Front view of model.

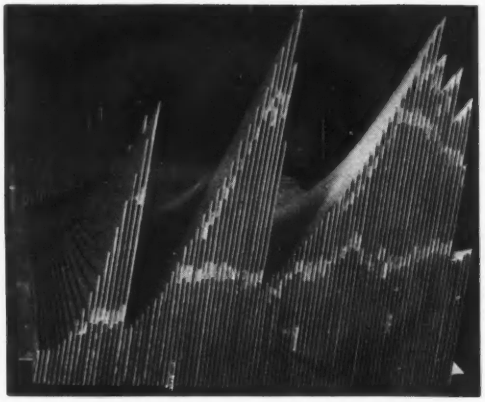

FIG. 2. Rear view of model.

significance show up conspicuously in this view. One sees also the abrupt discontinuities in absorption coefficient which accompany the onset of absorption in the successive shells. As a teaching aid the model has been most satisfactory.

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[1] Am. J. Phys. (Am. Phys. T.) **7**, 262 (1939).

An Experiment in Static Electricity

IN preparing to demonstrate the ionizing action of x-rays, three balloons were given frictional charges of electricity by rubbing with fur. However, in this particular instance, we found it impossible to produce enough charge to push the balloons apart the usual distance of a foot or two. The air in the room was dry and there seemed to be no reason why the experiment should not work. It was finally noticed that a metal stand with a pointed end, such as is used to support a compass needle, happened to be standing on the demonstration table underneath the balloons. When this was removed the balloons retained their charge.

This behavior suggested that a sharp point might be particularly active under these conditions. Accordingly the end of a $\frac{3}{8}$-in. brass rod 3 ft long was turned down in the lathe to a sharp point. On the other end was mounted a 2-in. brass sphere. Three balloons, blown up to a diameter of 20 to 22 cm with illuminating gas, were suspended by silk threads. The illuminating gas, being lighter than air, reduces the apparent weight of the balloons and hence makes them more easily deflectable. On rubbing them with fur they stood out from the vertical about 30 cm, arranging themselves at the corners of an equilateral triangle, as shown in Fig. 1. When the spherical end of the brass rod was held under the balloons, they were attracted to it due to the induced charge appearing on the sphere. When, however, the pointed end was held underneath, the balloons rather quickly fell together and were completely discharged. The electric field became so intense at the point that the air around it was ionized and ions of sign unlike that of the charges on the balloons flowed away from the point and neutralized the balloon charges.

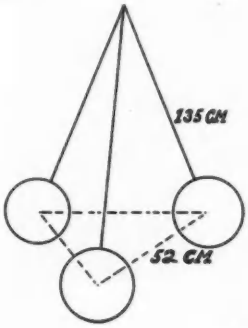

FIG. 1.

A simple computation yields the charge on the balloons and the current during the discharge. The weight of a balloon, blown up to a 20-cm diameter with illuminating gas, was about $\frac{1}{2}$ gm. In a typical case, the balloons, when hung from silk threads 135 cm long and charged, stood out 30 cm from the vertical, as in Fig. 2(a). The force F' needed to hold a balloon in this position is $\frac{1}{2}\times 980\times\sin 13°$ or 110 dynes. The electrostatic forces acting toward any vertex of the triangle ABC, Fig. 2(b), balance F'. Therefore, if F is the force of repulsion between any two balloons, $2F\cos 30°=110$ dynes or $F=63.5$ dynes. From the Coulomb law, one of a pair of charges 52 cm apart—the length of one side of the equilateral triangle in Fig. 2(b)—and producing a force of 63.5 dynes is -415 esu or -1.38×10^{-7} coulomb. The potential q/r is approximately -41.5 esu or $-12{,}450$ v at the surface of a balloon. This potential is still further lowered by the presence of the other two charges of -415 esu each. Since they are 52 cm away, the average potential of a given balloon is lowered by $2\times(-415)/52$ or -16 esu. Thus the total potential for any balloon is -57.5 esu or $-17{,}250$ v.

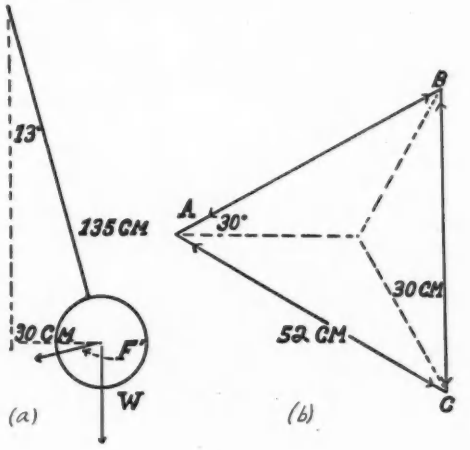

FIG. 2.

When the sharp end of the rod is brought into the region around the three charges they are neutralized by the ions of opposite sign in about a second. The average current thus generated is therefore $3\times1.38\times10^{-7}$ amp or 0.41 microamp.

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A Simple and Effective Device for Production of Lissajous' Figures with an Oscillograph

AN effective demonstration of the combination of alternating voltages at right angles and the resulting Lissajous' figures can be made with a cathode-ray oscillograph. A useful device for the production of the small alternating voltages, which are required, consists of two small magneto-type generators geared together and driven by a small variable speed motor.

Figure 1 shows some essential features of a magneto-type generator which can easily be constructed. The field magnet consists of one of the permanent horseshoe type magnets from an old telephone ringer. The pole pieces are made of soft iron, are cut so that they will partially surround the poles of the field magnet and are held in place by the friction and by a slight compression in the two brass cross pieces which serve as the armature bearings. The armature is made from a piece of $\frac{3}{4}$-in. Bakelite which is mounted on a $\frac{1}{4}$-in. iron shaft. The Bakelite is cut around two sides and two ends so that 3000 turns of No. 40 enameled wire can be wound on it. The ends of this coil are brought out to two small slip rings upon which contact can be made by wire brushes on each side of the armature.

The simple direct generation of the required a.c. voltages has a number of advantages. There is the direct pedagogic advantage in that the source of the a.c. is so well known to most students. The change in speed of rotation causes both the amplitude and frequency to vary, but the relative frequency, of course, remains fixed since the two generators are geared together. By running the combination very slowly, it is possible to see the point trace out the figure on the screen. The phase relationship is varied easily by changing the point of mesh of the gears, and the speed ratio is varied by interchanging gears. Small gears are readily available having simple integral ratios of pitch diameter.

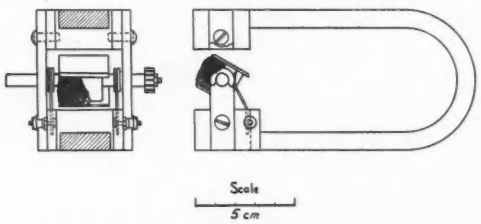

FIG. 1. Constructional features of the two-pole generator.

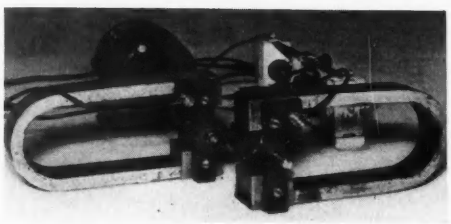

FIG. 2. Two of the magneto-type generators geared together for equal speeds.

Figure 2 shows two of the generators geared together for equal speeds and connected to a small variable speed driving motor.

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The Mirror-Backed Lens

A NUMBER of faint real images of a distant object can be found on the object side of a centered lens system. They are, of course, due to light reflected back through the system from various lens surfaces. The Purkinje images formed in the eye by reflection at the surfaces of the cornea and crystalline lens are of this nature.

Searle[1] and Southall[2] have discussed the general theory of what the former calls "thick mirrors," but the simpler aspects of these systems do not seem to have received the attention they deserve. I have always found it provocative of interest to point out the existence of such images to students in a general physics course, suggesting to the more enterprising members of the class that they work out the optics of the phenomenon for a simple case and check the result by experiment. Such a project provides a good review and application of the properties of mirrors and thin lenses.

Perhaps the simplest case is that of the image formed by light thrown back through a single thin lens of small aperture from its rear surface. The system approximates two thin lenses and a spherical mirror in contact. The focal length of the combination may be obtained at once from the "power" law or, more instructively, by working out the changes in direction of a ray from a distant source, using the law of reflection and the simple form of the law of refraction for small angles.

For a symmetrical lens of refractive index n whose surfaces are ground to a radius R, the focal length for returned light is readily found to be $f=-R/2(2n-1)$. The experimental test consists in measuring the radius of curvature of the rear surface of the lens, the combined focal length of the system and the ordinary focal length of the lens for transmitted light and substituting the values in the power law. If the refractive index of the glass is known, it is necessary only to compute the ratio of the two focal lengths, substitute this value and compare with the experimental result. Students usually have no trouble in verifying this relation to within about 2 percent.

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[1] G. F. C. Searle, Proc. Opt. Convention (London, 1926), II, pp. 825–9.
[2] J. P. C. Southall, *Mirrors, prisms and lenses*, pp. 376–84.

Measurement of an Ionization Potential

THE measurement of critical potentials offers a number of instructive atomic physics experiments suitable for advanced undergraduate or graduate courses.[1] For measuring the ionization potential of a gas, there is an especially simple effective experiment based on a method originally proposed by Langmuir. In the hands of our sophomore physics students this experiment has yielded results of satisfying accuracy. Cuykendall[2] has presented an excellent description of such an experiment, so the purpose of the present note is to call attention to certain minor differences in apparatus and to a significant feature in the results.

Briefly, the method consists in measuring the space-charge limited current I of a gas-filled diode as a function of the plate voltage V. In rough conformity with the Langmuir-Child equation, $I^{\frac{1}{2}}$ is approximately linear with V until the ionization potential of the gas is reached. At this point the increase in plate current due to space-charge neutralization by the resulting positive ions produces a sharp break in the curve. The ionization potential of the gas is given by the difference between the potential at the intercept of the linear curve on the V axis and the potential at the break in the curve.

The circuit shown in Fig. 1 is suitable for use with a tube having an equipotential cathode. The commercial type 884 triode, containing argon at a pressure of about 1 mm of mercury, can be used with grid and plate tied together for diode operation. The plate-current meter should have two ranges to measure currents from 1 to 50 ma with sufficient precision, and should not introduce a drop of more than 50 mv if meter corrections are to be avoided. A series resistance of 20 ohms suffices to protect the tube from excessive current, if an 18-v battery is used. The resistance of the potential divider should not be more than about 100 ohms.

The data presented in Fig. 2 were obtained and analyzed by two students during a regular 2-hr laboratory period. Both the point of onset of ionization and the intercept on the voltage axis are sufficiently well marked to be located with an uncertainty of about 0.1 v. A statistical analysis of 17 consecutive sets of data yielded for the ionization potential of argon a value of 15.91 ± 0.07 v, based on students' location of the intercept and break. This figure is to be compared with the accepted value of 15.69 v.

A significant feature of every set of data obtained with this apparatus is indicated in Fig. 2. The curve fitting the data in the space-charge region is *not* a straight line, as predicted by the Langmuir-Child equation, but is appreciably concave downward. This curvature is definite and consistent, having been obtained with an external electrostatic shield, with the plate grounded to serve as a shield, and with the tube highly evacuated. The curves given by Cuykendall[2] also show slight evidence of such curvature. The question of space-charge limitation has recently been re-examined by Frank,[3] who predicted a departure from linearity in the $I^{\frac{1}{2}}$ *vs* V curve for small values of anode potential in qualitative agreement with that described here.

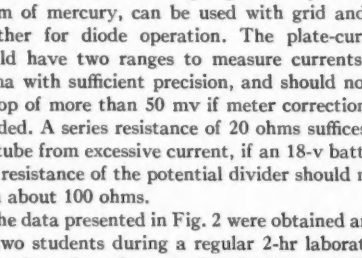

FIG. 1.

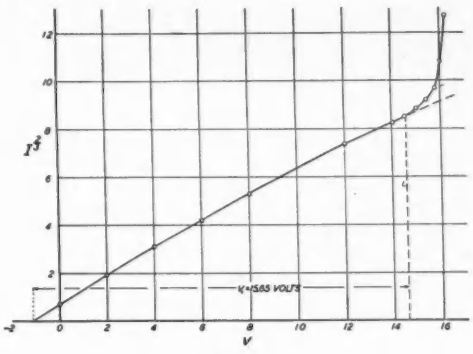

FIG. 2.

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E. S. LAMAR

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Massachusetts Institute of Technology,
Cambridge, Massachusetts.

[1] Harnwell and Livingood, *Experimental atomic physics* (McGraw-Hill, 1933), pp. 314–323.
[2] Cuykendall, Am. J. Phys. (Am. Phys. T.) **4**, 93–95 (1936).
[3] Frank, Am. J. Phys. **8**, 116–117 (1940).

The Presentation of the Thermionic Space-Charge Equation

THE recent note[1] "On the presentation of the thermionic space-charge equation" is most welcome to those who have lamented the careless treatment of this problem in many textbooks. There remains the pedagogic problem of presenting the situation with reasonable correctness and yet with simplicity. Even an outline of the accurate treatment[2] is mathematically complicated and can be presented only to graduate students. For this reason, it is of interest to consider an interpretation of the Langmuir-Child equation which may be given even to undergraduates. The following presentation offers students an unusually clear idea of the limitations involved in this "three-halves power law."

First, the usual derivation[3] of the Langmuir-Child equation is given. The two important assumptions are made quite explicit: (1) that $dV/dx=0$ at $x=0$, and (2) that all electrons leave the cathode with zero speed. The current density j_s at $x=d$ (that is, at the anode) is then given by

$$J_s=(1/9\pi)(2e/m)^{\frac{1}{2}}(V_s^{\frac{1}{2}}/d^2), \qquad (1)$$

where e/m is the ratio of charge to mass for the electron and V_s is the potential at $x=d$. It is clear from assumption

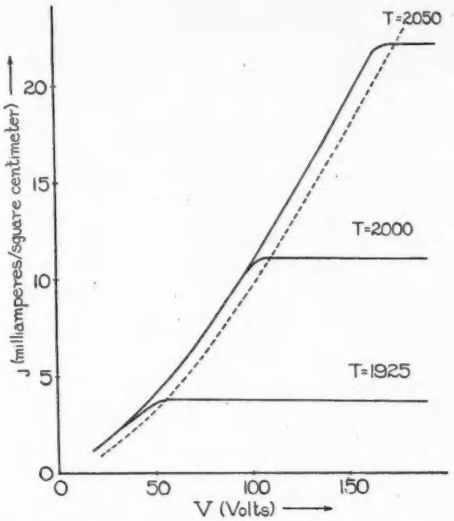

FIG. 1. Current-voltage curves calculated (see text) for parallel plane electrodes. The dotted line shows the Langmuir-Child relations.

(1) that all emitted electrons reach the anode so that j_s and V_s are, respectively, saturation current density and saturation plate voltage. (The subscript s is intended to remind the student of this limitation.)

Second, an interpretation of Eq. (1) as applied to experiment is discussed. An obvious suggestion is to regard the equation as that of the locus of saturation points on a series of current-voltage curves taken at various cathode temperatures. This is indeed almost the interpretation originally given by Child and by Langmuir, and it places a very proper emphasis upon assumption (1). However, the initial speeds of electrons in an actual case cause an appreciable diminution of the charge density (from the value used in the derivation mentioned), so that the value of V_s given by Eq. (1) for any value of j_s is a little too small. The situation can be seen in Fig. 1. There the solid lines represent current-voltage curves calculated by Langmuir's method for three temperatures of a cathode having a work function of 4.50 ev and being distant 0.5 cm from a parallel anode plane. The dotted line represents Eq. (1). It must be remembered that, in actual practice, the onset of saturation is less sharp than indicated here; this may be due to a Shottky effect, to cathode irregularities, and to other causes which are not directly concerned with space charge and which need not be mentioned at this moment to students.

Third, the concept of a virtual cathode is introduced to make clear an approximate relation for the space-charge limited current density j as a function of the corresponding anode potential V. For this case, $V(x)$ has a minimum V_m at $x=x_m$. Imagine the emitter replaced by a virtual cathode situated at x_m and emitting a number of electrons per second equal to the actual plate current (rather than the number emitted by the actual cathode). Suppose that these electrons leave the virtual cathode with zero speed. A brief discussion of the $V(x)$ graph will convince the student that, if we now measure potential from V_m and distance from x_m, the mathematical problem resembles that already solved for saturation current densities, so that

$$j=(1/9\pi)(2e/m)^{\frac{1}{2}}(V-V_m)^{\frac{1}{2}}/(d-x_m)^2. \qquad (2)$$

Of course, if $V_m \ll V$ and $x_m \ll d$, Eq. (2) approximates Eq. (1) and the actual current-voltage curve nearly conforms to a three-halves power law.

Finally, a numerical example indicates clearly the degree of approximation involved. Consider again two parallel, plane electrodes 0.5 cm apart. If the cathode temperature is about 2000°K and j_s is 0.0111 amp/cm², then

V(v)	j(amp/cm²)	V_m(v)	x_m(cm)
2.00	0.0001	−0.813	0.079
18.05	.0010	−0.415	0.022
97.5	.0100	−0.018	0.002
105.0	.0111	0	0

so that V_m and x_m can well be neglected for a considerable range of currents. In Fig. 2, which shows graphically the approximate validity of the Langmuir-Child equation for this case, the dotted line is a plot of Eq. (1), the dashed line a plot of Eq. (2) with the foregoing values of V_m and x_m, and the solid line indicates the true values. That the dashed line does not coincide with the true values indicates again the importance of assumption (2), for in "deriving" Eq. (2) initial speeds were neglected except insofar as these contributed to the existence of a potential minimum and to allowing certain electrons to pass this minimum. One further remark about approximations may be given. It has been shown[4] that results similar to the aforementioned hold for concentric cylindrical electrodes but that, in this case, due to the manner in which the

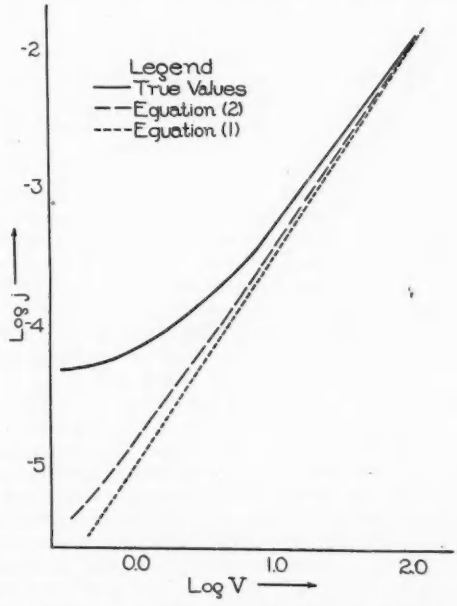

FIG. 2. Approximations in the equations for the particular case described in the text.

electric field varies with the radial distance, deviations from the three-halves power law are even less than for the case of parallel plane electrodes.

The usual derivation of the Langmuir-Child equation does not give a satisfactory account of space charge in a diode. But if the importance of velocity distribution in causing space-charge limitations is stressed and if, in addition, the concept of a virtual cathode is introduced to bridge the gap between saturation currents and space-charge limited currents and clear examples of the magnitudes of various approximations are offered, the student is not left with a vagueness concerning the validity of the three-halves power law.

HORACE GROVER

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[1] N. H. Frank, Am. J. Phys. **8**, 116 (1940).
[2] I. Langmuir, Phys. Rev. **21**, 419 (1923).
[3] The notation here follows quite closely that in Frank's paper to which one may refer for the derivation.
[4] I. Langmuir and K. Blodgett, Phys. Rev. **22**, 347 (1923).

Now, to Supplement the Textbooks

I SUPPOSE that the author of any physics textbook would be the last person to claim that it was up to the minute. Up to the year is quite as well as any textbook or bound volume can hope to attain. There is really no need for a physics textbook, covering the long development of this important branch of science, epitomizing the present accepted knowledge, to concern itself too rigorously with the very latest experimental finding hot from a cloud chamber. From a study of physics, one of the most important conclusions to which the student should come is that physics, like all other science, is and ever will be unfinished. Every textbook, every lecture, might very well be closed with the familiar (*to be continued*) line customary in our popular magazines.

If the teacher were expected to keep up with the latest Letters to the Editor in the *Physical Review*, it might well be that he would have too little time to accomplish his fundamental task of helping students obtain knowledge and insight into the principles and practices of this important branch of science. Far more essential than acting as a courier of the latest and most novel experimental intelligence is the development by the teacher of the attitude that the body of scientific facts and theories to which he is introducing his auditors is a living, evolving and changing portion of our knowledge.

The student can be told this in so many words without very much effect, just as he may read and even memorize a principle of physics without any real understanding of what it means. For him to comprehend effectively a fundamental idea in physics, an experiment should be performed in the laboratory. To make him realize that the physical world is not finished, the student can be brought into contact through the periodical literature with reports of the latest developments in physics. This can be done by guiding him to the various channels of collateral periodical reading, not alone in the narrow field that is labeled "physics," but all related categories into which, with increasing frequency, advances in physics are creeping and bringing about important effects.

From the articles that collate and predigest the more technical papers which appear over a period of time in the various niches of physics—such papers as are published in several of the journals of physics—the more advanced student can obtain a factually exciting and inspiring panorama of what is happening in that particular sector. There is always the chance that goaded by these fresh developments, which seem much closer to the present than the material in the textbook, the student will delve even deeper than the review article and begin to dig out some of the bibliographical references. The urge may be so great in a few exceptional cases that he will be forced to start some laboratory work in the field. Such blossomings of research are rare but precious.

For the less advanced student, who may have been told repeatedly that science is important in the workaday world but who may not be convinced emotionally that it is, the briefer and more timely news report of advances in the physical sciences, such as appear weekly in the *Science News Letter*, may be the inspirational catalyst which will elevate a physics course from the routine channels of the educational process. Hardly a week has passed during the exciting years of physics through which we have been living without a development or two that has the chance of sending the student back to his textbook, making him dig into reference books, ask the professor questions about some new development. Because the simplified and clarified accounts of advances in physics that appear in the *Science News Letter* are written primarily for the layman in physics (with the thought that often the biologist or psychologist or other nonphysicist is as much a layman in physics as a taxicab driver or a lawyer), the student probably will not have to look up in his textbook any of the words or explanations of principles. Rather, if he is inspired to know more, he will be searching for the background and the antecedent of the present development which at most can only be hinted at in the short current account. Though our hypothetical student whom we thus visualize may well be of the rare sort that is a joy to any professor's heart and mind, the average or normal student to whom the current reports of physics are made available may very well derive knowledge, inspiration and added interest from merely reading them and doing nothing more about it. A periodical article may very well relate a fruitful experiment with the cyclotron to the fundamental treatment of atomic physics in the textbooks. A new advance in metallurgy may very well be linked in the student's mind with some of the fundamentals of mechanics.

There have been exciting spurts in discoveries in physics in recent years; for example, when atomic bombardment was making element after element artificially radioactive, when early in 1939 the fission of the uranium atom revived the dream of atomic power, when the disguise of cosmic rays began to be penetrated. The student who is not given opportunity through collateral periodical reading to follow these developments while he is studying physics, loses an enriching experience which he should have to round out his fundamental studies of the classroom.

WATSON DAVIS

Science Service,
Washington, D. C.

Proceedings of the American Association of Physics Teachers

THE UNIVERSITY OF WASHINGTON MEETING, JUNE 18–21, 1940

The third meeting of the American Association of Physics Teachers on the Pacific Coast was held at the University of Washington, Seattle, on June 18–21, 1940, in connection with the annual meeting of the Pacific Coast Division, American Association for the Advancement of Science and Associated Societies. The program committee for the meeting consisted of A. A. Knowlton, *Chairman*, A. E. Caswell, R. S. Minor, F. A. Osborn, R. R. Tileston and W. Weniger.

On June 18 a morning session and an afternoon joint session with the American Physical Society were devoted to the following invited papers:

Some Demonstrations with Polarized Light. FRANCIS T. JONES, *Pacific University, Forest Grove, Oregon.*

The Life and Work of William Gilbert as Portrayed in Old Prints. E. C. WATSON, *California Institute of Technology, Pasadena, California.*

Physics of the Solar System. JOSEPH KAPLAN, *University of California, Los Angeles, California.*

The C. A. A. Ground School. DAVID L. WEBSTER, *Stanford University, Stanford University, California.*

The Training and Prospects of the Ph.D. in Physics. RAYMOND T. BIRGE, *University of California, Berkeley, California.*

The Training of Physicists for Industry. W. WENIGER, *Oregon State College, Corvallis, Oregon,* and W. E. FORSYTHE, *Nela Laboratories, Cleveland, Ohio.*

Some Statistics About American Physicists. A. A. KNOWLTON, *Reed College, Portland, Oregon.*

CONTRIBUTED PAPERS

Abstracts of papers contributed at sessions on June 21 are as follows:

1. The Significance of Symbols in Physical Equations. V. F. LENZEN, *University of California, Berkeley, Calif.*—In contemporary physics it is uncertain whether symbols in equations designate numerics or physical quantities. The interpretation of symbols as designating physical quantities is set forth by the method of Wallot. In this system a quantity is expressed as equal to a number times a unit. The objection that the operations of multiplication and division apply only to numbers is not valid, because mathematical operations upon any objects whatsoever can be defined by postulates. In Wallot's system the ratio of the absolute electromagnetic and electrostatic units of electric charge is a pure number. On the operational theory of physical concepts, however, quantities are defined by methods of measurement and the symbols should symbolize the results of operations and not independent realities. It therefore appears to be advisable to adopt the view of Helmholtz, recently revived by J. Fischer, according to which symbols designate labeled numbers. If we provide the numerical measure with its label, and adopt postulates for operations with labels, the mathematical procedure is the same as for the theory that symbols denote quantities.

2. The New Electronics Laboratory at the California Institute of Technology. W. H. PICKERING AND H. V. NEHER, *California Institute of Technology, Pasadena, Calif.*—A new laboratory course in electronics, put into operation in March, 1939, is intended to give senior and graduate students of engineering and physics experience in dealing with various electronic devices illustrating fundamental physical principles. Since many such experiments involve periodic phenomena which are best studied with the aid of oscilloscopes, 7 3-in. oscilloscopes are available for use in 10 different experiments. The subjects covered include transients, the piezoelectric effect, audiofrequency amplification, radiofrequency amplification, radiofrequency oscillators, modulation, thyratrons, relaxation oscillators, Geiger counters and properties of vacuum tubes. To lessen the routine of making connections, all meters, condensers, tube bases and other equipment are mounted on one or more "Masonite" boards. All permanent connections are made under the board. A complete wiring diagram in white paint is made on top with conventional symbols for resistances, condensers, etc. so that the student can see all connections at a glance. Where it is necessary to change values of resistances, capacitances or chokes, provision is made to simply plug in the desired value. Separate power supplies are available for each experiment and all meters are fused. A simple type of harmonic analyzer was described that permits the total harmonic content introduced by an amplifier to be read directly from a meter.

3. A Compensating Audio Pre-Amplifier. A. W. NYE AND P. L. BATEMAN, *University of Southern California, Los Angeles, Calif.*—A frequency compensating preamplifier was constructed to provide audio compensation at four frequency bands near 40, 80, 1250 and 6000 cycle/sec, the purpose being to provide a device for correcting the bass of a public address loudspeaker with insufficient baffle area, for compensating unsatisfactory microphone performance, for altering the response of any amplifier, etc. The amplifier provides discrete frequency-band compensation by utilizing the fact that at low plate loads the gain of a pentode is directly proportional to the plate load. By inserting appropriately tuned, parallel L–C units in the plate circuit of a 6C6 tube the frequency at which the maximum gain could be obtained depended on the relation $f=1/2\pi\sqrt{(LC)}$. The zero-compensation voltage gain was 19.5 db, while the possible voltage gains at 40, 80, 1250 and 6000 cycle/sec were 22, 18, 10 and 13 db, respectively. One series of tests showed that when used ahead of a 15-w amplifier, the range of the latter was extended down from 70 to 30 cycle/sec.

4. Quantitative Experiments on Directional Antennae. E. A. YUNKER, *Oregon State College, Corvallis, Ore.*—A method was described for quickly setting up for class demonstration various types of directive antenna arrays, such as broadside, endfire and stacked systems. The elements of these arrays are half-wave radiator units mounted on convenient supports. Energy is supplied by feeder systems driven by a 2.5-m oscillator. Measurements of gain

and determination of radiation pattern are readily made. Field strength is determined by instruments read from a distance through telescopes.

5. Modern Physics as a Second-Year Course in Physics. J. J. BRADY, *Oregon State College, Corvallis, Ore.*—As a second-year course, modern physics offers several advantages. The subject matter forms a natural sequel to that of general physics, both historically and in order of difficulty; it completes a preliminary view of the entire field. The course is of interest and service to the student taking physics as a general culture subject as well as to the future physicist or engineer. If desirable from the standpoint of student-programs, the subject matter can be arranged so that a student may enter any term. An outline of the course in use at Oregon State College was given, and the procedures followed in several other institutions were indicated.

6. A Laboratory Course in X-Rays. PAUL KIRKPATRICK, *Stanford University, Stanford, Calif.*—An x-ray laboratory course of intermediate grade is given in this institution to physics majors and others. The list of available experiments includes wave-length measurement by photographic and ionization spectrometers, determination of h/e by Duane and Hunt's relation, continuous spectrum characteristics, absorption laws, crystal analysis by several methods, total reflection and refractive indices of the elements, determination of e by grating and crystal wave-lengths, determination of h/mc from the Compton shift, studies of the Moseley law both for absorption limits and emission lines. Equipment and procedures were described and illustrated.

7. Photography as a College Subject. J. C. GARMAN, *Oregon State College, Corvallis, Ore.*—Photography has been taught at Oregon State College since 1919. Organized course work covers a two-year period, with an additional one-term course for those who present neither college physics nor chemistry. The object is to train students to use photographic equipment with an understanding of its scientific background, as an aid in their various special fields of interest. The laboratory is especially designed for photography and consists of 10 rooms: 2 dark rooms, 3 special purpose rooms, and 1 each for chemicals, printing, washing and drying, enlarging and copying. Most of the rooms accommodate 9 students at a time. Individual work is required but the student has the advantage of working along with others. Available laboratory space can be used to capacity. The system is economical and efficient from the standpoint of both student and instructor. A few advanced students assist in the campus photographic service.

8. What Systems of Units are to be Taught in First-Year Physics? WM. R. VARNER, *Oregon State College, Corvallis, Ore.*—Twelve systems of units are in use—6 systems for mechanics and 6 for electricity and magnetism. Those for mechanics are based primarily on Newton's second law; those for electricity are special cases of a basic system dependent upon a generalized form of the Coulomb law. The suggestion is made that first-year students be given an introduction to both generalized systems but that they concentrate in mechanics upon the four systems now in use—the absolute and gravitational variations of both the cgs and fps systems—and, in electricity, upon the mks unrationalized system.

9. A Modified Sonometer Experiment. MARCUS O'DAY, *Reed College, Portland, Ore.*—The sonometer experiment is more instructive and easier to perform if the wire is driven electrically. The output of a beat-frequency oscillator is connected to the wire through an appropriate amplifier. If the wire is placed in a steady magnetic field, oscillations of large amplitude occur when the frequency of the alternating current corresponds to a natural mode of vibration of the wire. An inexpensive sonometer of this type was demonstrated, using a gas-filled relaxation oscillator. Calibration is accomplished by means of the 60-cycle sweep and modified Lissajous figures formed on the screen of a built-in 913 oscillograph tube. A calibrated spring furnishes the tension. The amplitude of vibration of the wire is sufficient to show a visible indication of harmonics as high as the fifth. The laws of vibrating strings are readily demonstrated.

10. Application of Electronics to the General Physics Laboratory. MARCUS O'DAY, *Reed College, Portland, Ore.*—The cathode-ray oscilloscope has many uses other than the demonstration of wave forms; in conjunction with standard condensers and a "saw-tooth" oscillator it can be used to measure the inductance of chokes, transformers, windings, etc.; by means of Lissajous figures it can be used to compare frequencies; with a calibrated screen it is a good "zero-current" voltmeter. The gas discharge tube can be used as a convenient variable audiofrequency oscillator for sound experiments such as a modified Kundt tube and the resonance of closed pipes. The ordinary 2-w neon glow tube can be used to protect meters and as a continuity indicator drawing very little current; the comparison of the periods of two pendulums by the method of coincidences is a simple illustration of the use. An intense source of semi-monochromatic light making use of a radiofrequency arc from fused salt was demonstrated.

11. Second Differences in Acceleration Experiments. W. WENIGER, *Oregon State College, Corvallis, Ore.*—In some acceleration experiments, such as that of the falling tuning fork, the acceleration is obtained from the second differences of the recorded data. The question as to the best method of computing the average second differences is of considerable interest. A number of methods were discussed. The most accurate value of the acceleration results if both the first and the second differences are obtained by the method of "group differences" or "half-column differences"; that is, by dividing the column of figures (preferably taken so that the number of items is some multiple of four) into upper and lower halves and subtracting the first item in the upper half from the first in the lower, the second in the upper from the second in the lower, etc.

12. A Scanning Device for Plotting Equipotential Lines. JOHN SIMPSON, *Reed College, Portland, Ore.*—To shorten

the time required to plot the equipotential lines of an electrode system in an electrolytic bath, apparatus was devised that makes the recording of the selected lines automatic. The usual arrangement of a shielded probe attached to the arm of a pantograph which moves over a drawing board was employed. The new feature is the replacement of the ordinary null point indicators by an electronic circuit operating a sensitive relay in such a way that the relay is open only when the probe is on a chosen equipotential line; thus, as the probe scans an extensive region, the relay opens only at points on this line. The speed of the relay is such that about 80 equipotential crossings per minute may be determined. A scale record of the lines is made by a metal stylus moving over chemically treated paper; the relay completes the circuit through the stylus, paper and drawing board. The scanning motion of the probe can be motor controlled.

13. A New Type of Search Coil for Ballistic Measurement of Magnetic Field Strength. JOHN SIMPSON, *Reed College, Portland, Ore.*—A device by means of which one can quickly and accurately measure the field intensity in any part of a magnetic field was described. A small search coil encased in a shuttle is moved along a brass tube by the action of compressed air. A conventional ballistic galvanometer circuit is used for calibration and measurement. This apparatus is a modification of the common snatch coil method for measuring magnetic field intensities. Its advantages lie in the fact that the search coil can be instantly replaced at any desired point in the field, and points in a confined space are easily reached. The rapidity of making a series of measurements is limited only by the period of the galvanometer. Since the unit is self-contained and positive in action it is a useful addition to standard laboratory equipment. Field distributions of a magnetic electron lens were given to demonstrate the advantages of the method.

14. An Electronic Voltage Regulator for a Small Direct-Current Generator. G. G. KRETSCHMAR, *Walla Walla College, College Place, Wash.*—Because of the variable frequency of the electric supply system, the voltage of the motor generator set in this laboratory was subject to rather large and disagreeable voltage fluctuations, even without any change of load. This has been corrected by means of an electronic voltage regulator with very satisfactory results. The regulation is accomplished by the application of the controlled output of a single F.G. 57 thyratron tube across the shunt field rheostat of the generator. The circuit is made up of conventional circuit elements and the operation is very satisfactory, giving a regulation closer than 0.5 percent without regard to changes of load or frequency.

Appointment Service

REPRESENTATIVES of departments or of institutions having vacancies are urged to write to the Editor, Columbia University, for additional information concerning the physicists whose announcements appear here or in previous issues. *The existence of a vacancy will not be divulged to anyone without the permission of the institution concerned.*

POSITIONS WANTED

29. Ph.D., Northwestern; M.S., Pittsburgh; A.B., Muskingum. Age 34, married, 1 child. Has had 13 yrs teaching experience in two universities. Interested in teaching and research.

30. Ph.D., Univ. of Chicago. Many years experience as head of department of physics in prominent college. Author of books on physics and history of science. Large work on history of physics in preparation. Interested in college or university teaching.

31. Ph.D., Columbia. Years of experience as head of departments of physics in colleges and universities. Author of new type of laboratory manual. Designer of many new types of simplified apparatus. Research in radio, acoustics and methods of teaching physics.

33. M.S., experimental physics, coupled with thorough background of courses in professional education. Has taught physics and mathematics for 3 yrs in large high school. Desires position as instructor in high school physics in a university or college experimental or training school.

34. Ph.D., M.S., Penn State. Age 38, married. 13 yrs teaching experience in colleges and universities; 3 yrs head of department in small college; industrial research experience. Interested in teaching, research and administrative work in a small college.

35. Ph.D., Purdue; M.A., British Columbia. Age 27, married. Experience: 5 yrs university teaching; 2 yrs secondary school teaching; 5 yrs research in analysis of liquids by x-rays. Interested in teaching and research.

37. Ph.D., engineering physics, mathematics and physical chemistry, Illinois; A.B., education. Age 37, married. University, teachers college, junior college and high school experience; 1 yr editorial work. Especially qualified for survey courses.

38. M.S., physics, Lehigh. Age 35, married. 10 yrs teaching college and university, particularly laboratory instruction. Interested in college teaching, or in industrial production and developmental work in precision instruments.

39. Ph.D., physics, large Eastern university. Age 45, married. 16 yrs university and college teaching experience, including 9 yrs head of physics department of a small liberal arts college. Research in optics and spectroscopy. Desires opportunity for research in teaching or industrial fields.

40. Teacher, 12 yrs experience, 6 in American schools in Europe and 6 in colleges and university. Ph.D. in physics, Stanford. Married, age 35. Seeks position requiring skill in teaching, ability in experimental research and interest in developing courses.

VACANCIES

1. Student machinists, instrument makers and woodworkers to work for their tuition in the physics shop, Muskingum College, New Concord, Ohio.

2. Instructor, immediately. Salary $2000. Should be Roman Catholic.

Departments having vacancies or industrial concerns needing the services of a physicist are invited to publish announcements of their wants; there is no charge for this service.

Any member of the American Association of Physics Teachers may register for this Appointment Service and have a "Position Wanted" announcement published without charge.

RECENT PUBLICATIONS AND TEACHING AIDS

METEOROLOGY

The Meteorological Glossary. Ed. 3. Meteorological Office, British Air Ministry. 251 p., 36 fig. and maps, many tables, 14×22 cm. *Chemical Publishing Co.*, $3. This is the first American edition of a comprehensive and up-to-date glossary of the terms and concepts of meteorology, prepared and recently revised by the technical staff of the British Meteorological Office. The terms are arranged alphabetically, with many cross-references, and are accompanied by definitions and explanations that vary in length from a sentence to several pages. An appendix lists the equivalents in nine foreign languages of approximately 300 of the terms.

BOOKS FOR SECONDARY SCHOOLS

Physics of Today. JOHN A. CLARK, Chairman of Standing Committee on Science for Public High Schools of New York City; FREDERICK RUSSELL GORTON, Head of Department of Physics and Astronomy, Michigan State Normal College; AND FRANCIS W. SEARS, Assistant Professor of Physics, Massachusetts Institute of Technology. 649 p., 750 fig., 23 plates, 9 tables, 13×20 cm. *Houghton Mifflin*, $1.80. Fundamental material and important applications are stressed in a simple, brief and interesting way.

Experiences in Physics. LESTER R. WILLIARD AND CHARLES S. WINTER, Thomas Jefferson High School, Elizabeth, N. J. 672 p., many diagrams and photographs, 17×23 cm. *Ginn*, $1.92. Intended to serve both as a text and as a manual of experiments, this book presents elementary physics through an extensive series of very simple demonstrations or "experiences," each accompanied by questions and followed by a brief discussion of the principles involved. The plan is adaptable either to a single- or to a double-period laboratory schedule.

Our Physical World. CHARLES F. ECKELS, CHALMER B. SHAVER AND BAILEY W. HOWARD, Department of Physical Science, Pasadena Junior College. 812 p., 438 fig. and plates, 14×21 cm. *Sanborn*, $2.20. Material for a year's course in general physical science is provided.

The Development of Power. EUGENE C. WITTICK. 178 p., 148 fig., 15×23 cm. *University of Chicago Press*, cardboard cover, $1. Developed in the Laboratory Schools of the University of Chicago as one of a series of units for learning and teaching purposes, this publication provides useful, concise information on the history and modern applications of various energy sources, engines and methods of transmitting energy. This material is assembled under the headings: wind, water, steam, internal combustion, electricity and transmission.

PAMPHLETS

Bell System Technical Publications. *Bell Telephone Laboratories* (463 West St., New York), gratis to departments. (1) H. FLETCHER, *Auditory Patterns*, Mon. B-1205, an address presented at the joint meeting of the American Physical Society and American Association of Physics Teachers, Washington, December, 1938 [reprinted from Rev. Mod. Phys. **12**, 47 (1940)]. (2) R. M. BOZORTH, *The Physical Basis of Ferromagnetism*, Mon. B-1200 [reprinted from Bell Sys. Tech. J. **19**, 1 (1940)].

Standard Frequencies and Other Services Broadcast by National Bureau of Standards. LC-565. 5 p., mimeographed. *National Bureau of Standards* (Radio Sec., Washington), gratis to physicists. A description of the services broadcast from station WWV, which include: standard radiofrequencies; standard time intervals in the form of second-pulses; standard audiofrequency; standard musical pitch, 440 cycles/sec; bulletins on the ionosphere and radio transmission conditions.

PERIODICALS

Philosophic Abstracts. (844 Riverside Drive, New York), $4 per year. A new quarterly review of philosophic books and periodical articles in the form of brief excerpts and synopses.

The School Science Review. Edited by G. H. J. ADLAM (City of London School, Marlborough College, Wilt., Eng.), 10s. per year. Published for the Science Masters' Association and the Association of Women Science Teachers of Great Britain, this useful and admirable quarterly journal is now in its 21st volume. It publishes articles, reviews, correspondence, and notes on apparatus and demonstrations of interest to teachers of the various natural sciences in schools and colleges.

Science News Letter. (2101 Constitution Ave., Washington, D. C.), $3 per year to members of the American Association of Physics Teachers. A 16-page illustrated weekly review of what is new in science.

MOTION PICTURE FILMS

(a) Air Waves, (b) Television. Each reel is 16- or 35-mm sound film, 10 min. *William J. Ganz Co.* (19 E. 47th St., New York), loaned gratis. These two reels were produced under the sponsorship of Radio Corporation of America, National Broadcasting Company and RCA Manufacturing Company. *Air Waves* is the story of radio broadcasting, showing early developments, modern radio studios, and preparation and presentation of actual programs. *Television* shows how televised programs are produced and broadcast.

How Motion Pictures Move and Talk. 16-mm sound film or silent, 25 min. *Bell and Howell Co.* (1801 Larchmont Ave., Chicago), loaned gratis. The historical development and the production of motion pictures, with explanations of how the sound is recorded on and reproduced from the film, and how motion is implied on the screen.

Phenomena of Nature. Each subject 1 reel, 16 or 35 mm, sound or silent. *UFA Educational Films* (729 Seventh Ave., New York), rental or sale. (1) *Moving x-rays*: discovery and modern uses of x-rays; shadowgraphs of animal actions and of the articulation of the bones, beating of the heart, and peristaltic movements of the stomach and intestines of man. (2) *Liquid air:* liquefaction of air, neon, hydrogen and helium; apparatus; magnetic properties of liquid oxygen, etc.

You Can Make Good Movies. Each subject 1 reel, 16 mm, silent. *Harmon Foundation* (140 Naussau St., New York), rental, $2 per film. (1) *How to use your camera*, (2) *Common mistakes and their correction*, (3) *Exposure and exposure meters*, (4) *Film editing*.

DIGEST OF PERIODICAL LITERATURE

Apparatus and Demonstrations

An economical method of making lantern slides. G. H. Bell; *J. Sci. Inst.* **16**, 379–380 (1939). The cost of preparing lantern slides of line drawings and halftone plates may be considerably reduced by the use of paper negatives. Quarter-plate cut-film sheaths loaded with Kodaline Paper Slow (supplied by Kodak Ltd.) are inserted in plate holders, care being taken to avoid bending the paper. An exposure of about 3 min at f:11 is satisfactory for copying half-page illustrations with illumination from four 100-w lamps placed just behind the camera lens. The plate-holder slide is not fully drawn out so as to avoid buckling the paper when it is closed at the end of the exposure. The negative is developed for 2–3 min in a developer recommended by the manufacturer and should be pure black and white when the process is completed. It is printed by contact on gaslight lantern plates, using a mask with a 3 in. square opening to avoid fogging the edges. For a printing box with a surface intensity of 65 ft-c, approximately 8 sec exposure time is required. The plates should be developed in an energetic developer and the resulting slide should have black lines on a perfectly clear background. With suitable exposure times, the reproduction of line diagrams by this method is excellent. The reproduction of halftone plates depends on the fineness of the screen, the degree of reduction and the resolution of the camera lens; with care in printing, good slides are obtained. Advantages of this method, in addition to reduced cost, are the negligible storage accommodations required for the negatives and the ease with which unnecessary parts may be obliterated with an ordinary pencil.—H. N. O.

The deviation produced by a biprism. C. M. Focken; *J. Sci. Inst.* **17**, 42 (1940). The separation between the slit images in Fresnel's biprism arrangement is usually determined either by (1) the use of a convex lens to form magnified and reduced images of the slits when the microscope and slit are a fixed distance apart, or (2) the determination of the biprism angles with a spectrometer or goniometer. From the latter measurement, together with the refractive index of the glass and the distance from slit to biprism, one may calculate the separation between the images. Two simple modifications of method (2) have been adopted for student experiments: (*a*) the total deviation for light incident normally on the biprism is measured by a spectrometer reading to 10″, and (*b*) a horizontal, distant scale is viewed through the biprism placed in front of the objective of a telescope, adjustment for no parallax being made; when the vertical cross-hair is opposite the biprism edge, two images of the scale are seen by a negligible horizontal motion of the eye, and the deviation is found from the distance read on the scale between the two positions of the cross-hair. With deviations of approximately ½°, students obtain an accuracy of about 1 percent by either method (*a*) or method (*b*). Although the measurement of the distance from slit to biprism, necessary in method (2), introduces a small error, the accuracy of this method is higher than that for method (1), which is more commonly used. Careful comparison of results by modifications (*a*) and (*b*) has indicated that the accuracy of (*b*) is about twice as high as for (*a*); in addition, the observations are made more quickly and easily.—H. N. O.

The velocity of sound in air at temperatures below 0°C. A. E. Bate; *J. Sci. Inst.* **17**, 68–69 (1940). The resonant frequencies of a bottle-pipe resonator are given by the equation[1]

$$[\tan (2\pi l_1/\lambda)][\tan (2\pi l_2/\lambda)] = (r_1/r_2)^2, \qquad (1)$$

in which λ is the wave-length, l_1 and l_2 are the lengths, and r_1 and r_2 are the radii of the pipe and bottle portions, respectively. Equation (1) shows that two resonators, identical except for bottle lengths, will resonate to the

same frequency if these lengths differ by one-half wave-length. To measure the speed of sound, two such resonators are joined as shown in Fig. 1. Resonance is excited by blowing across the open ends, and tuning is effected by adjusting the length l_1, telescopic pipes being used. To eliminate the "pulling" of one resonator by the other, the mouths, which terminate in a common flange, are covered by a disk that may be rotated to expose either resonator to the exciting jet which is mounted on the disk. The pipe length is varied until the two resonant frequencies are the same. The wave-length must then be 16.8 cm and, by a determination of the resonant frequency, the speed of sound is obtained. For speed determinations at low temperatures, the apparatus must be immersed in some refrigerant. The necessary exposure of the upper portions of the resonators does not alter the method, for the effect of any temperature change along the pipes will be the same for both resonators. For carbon dioxide, a value of 283 m/sec was obtained with a possible error of 1 percent. The tube correction for the bottle diameter was minimized by the high frequency used, about 1685 cycle/sec.—H. N. O.

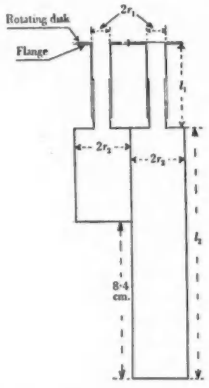

FIG. 1. Section through resonators.

[1] Nature **128**, 270 (1931); Phil. Mag. **16**, 562 (1933).

Two demonstration devices. J. S. MILLER; *Sch. Sci. and Math.* **40**, 155, 272 (1940). (1) *Heat generated by a spark; fixation of nitrogen and the resultant diminution in pressure.* To the side-tube of an exhaustion flask is attached an oil manometer. A two-hole stopper which fits the flask tightly supports two electrodes that are energized either by a Ford coil or an electrostatic machine. When a spark is passed the manometer immediately shows an increase in pressure due to heat generated by the spark. If the spark is stopped after running for a number of seconds, the manometer returns immediately to its initial level, and then more gradually assumes a lower level on the atmospheric side, thus indicating a diminution of pressure within the flask. The manometer fluctuations can be rendered more plainly visible by placing behind the manometer a white cardboard with several horizontal rulings.

The students will be able to account for the first phenomenon observed, but the second is likely to be a stumbling block for many. It can then be explained that $N_2+O_2 \rightarrow 2NO$ and $2NO+O_2 \rightarrow 2NO_2$, and that the decrease in the number of molecules predicted by the second of these relations accounts for the diminution in pressure.

(2) *Impact apparatus.* The horizontal track consists of a 6-ft length of angle-iron. Smoothly joined to it at one end is a similar piece of track, the inclination of which is varied by moving a supporting block at the farther end. For collision balls, old pool or billiard balls serve admirably; they are highly elastic, add color to the experiment and may be had for the asking at pool or billiard rooms.—D. R.

An apparatus to demonstrate the kinetic molecular theory of gases. L. DE ST. PAËR; *Sch. Sci. Rev.* **21**, 1010–1013 (1940). A box about 1 ft square and 2 ft high is made with a glass front. A square iron plate is mounted horizontally inside the box on four stiff coil springs, so that it can vibrate vertically. It is driven by a horseshoe electromagnet, mounted vertically below it. Current to the magnet is provided by a secondary battery and is interrupted periodically by a short length of steel clockspring attached to the plate and making contact with an adjustable screw; a rheostat in the circuit controls the amplitude of vibration of the plate. The top of the box is a square of plywood, supported by a string which passes over pulleys to a counterweight. About 50 ping-pong balls, to represent molecules, are laid on the iron plate, the top is pushed down onto the balls and the plate is set into vibration. The impact of the balls drives the top upward; by the addition of small weights, the top may be brought to equilibrium at different levels, illustrating pressure-volume changes (Boyle's law). Temperature change is represented by varying the amplitude of vibration of the plate. A small rubber balloon, partly inflated, may be introduced among the balls to demonstrate the cause of Brownian movements. Dalton's law of partial pressures may be illustrated by using first a smaller number of ping-pong balls, then some heavier rubber balls, and finally both together; in each case the volume is made the same by the addition of weights to the top. A vertical partition with a hole in it may be used to show diffusion; the lighter and faster-moving ping-pong balls pass through the hole more often than the heavier rubber balls. The whole apparatus should be mounted on a heavy base which can be clamped to the lecture table. The noise is terrific!—J. D. E.

A NEW FIELD FOR PHYSICISTS

The analytical physicist. E. HUTCHISSON; *J. App. Phys.* **11**, 301 (1940). Because of the analytical possibilities of such physical tools as spectrographs, x-ray and electron diffraction cameras, mass spectrographs and Geiger counters, a new profession—that of an analytical physicist—seems to be in the making. Educators must consider the matter of training students in technics of spectroscopy, x-rays, electronics, etc., and of informing industrial executives that specialists in the analytical technics of physics are available, so that industry will not be disappointed by the failure of these technics as a result of

inadequate knowledge and inexpert handling. Since many analytical physicists probably would not be called upon to engage in fundamental research, the profession should have attractive possibilities for the student who is interested in physics and yet is unable to continue his studies in the graduate school.—D. R.

Laboratory Objectives

Aims of the laboratory. M. Kostick; *Sch. Sci. and Math.* **39**, 760–763 (1940). If teachers would take time to crystallize their aims into a formula of action, the superiority of the laboratory method would be clearly evident. A list of aims for teaching by the individual laboratory method follows: (1) to have the student plan a course of action before beginning work; (2) to confront the student with a new environment by providing opportunity to (*a*) use individual resourcefulness and initiative, (*b*) make errors and see how the results are affected, (*c*) develop self-confidence, (*d*) experience the thrill of discovery; (3) to give the student direct and valid vocational guidance (that is, the chance to try being a scientist); (4) to give the student a fuller understanding and appreciation of the tasks and achievements of the laboratory worker; (5) to produce consciousness of the limitations of experimental methods; (6) to strengthen the bond between theory and practice; (7) to encourage patience, courage and perseverance though the success may not be immediately evident; (8) to correct undesirable individual differences; (9) to develop a sense of accuracy; (10) to appreciate and practice cleanliness and orderliness in the work; (11) to impart a more intimate understanding of scientific tools and materials; (12) to acquire some specific laboratory technics.—D. R.

"Basic Physics"

Basic physics as a part of mathematics. A. Hazeltine; *J. Eng. Ed.* **30**, 699–703 (1940). By *basic physics* the author, a professor of physical mathematics, means that part of physics "which is directly based on observations, without the intermediary of hypotheses. . . . the physics of gross matter, in contradistinction to atomic physics. It includes in increasing concentric circles the subjects of geometry, kinematics, mechanics, electricity and heat." The article describes a freshman course in "Engineering Problems" given in the physics department of Stevens Institute of Technology that involves "the presentation of *all* basic physics . . . in the logical way that characterizes mathematics and is now customary in geometry." —D. R.

Teacher Training

A professional laboratory course for science teachers. G. P. Cahoon; *Sci. Ed.* **24**, 64–67 (1940). The department of education of the Ohio State University offers a course designed to give prospective science teachers experience with such technics as glass blowing, wood- and metal-working, chemical processes, electric circuits and devices, and photographic and visual aids as related to apparatus, materials and tools used in secondary school science courses.

On the training of teachers for secondary schools. B. W. Jones; *Am. Math. Mo.* **46**, 428–434 (1939). Because a master's degree is becoming increasingly necessary for prospective secondary school teachers and because it is seldom necessary for such students to take as much work as the doctor's degree requires, it seems desirable to consider the principles underlying a program, complete after one year of graduate work, that will prepare a student to continue his education on his own initiative. The master's degree is usually considered only as a stepping stone for the doctorate, though for many it may be the last step. But any program for training teachers must be tied to what they are to teach, and it is necessary to examine the differences between the needs of prospective secondary school teachers and those of students who are preparing for research. Breadth of knowledge and ability to carry on investigations are soon dissipated for the average teacher if the knowledge and investigations are too far separated from what he teaches. The path to research is usually a narrow one, whereas the teacher needs breadth of outlook. Good teaching is not incompatible with investigation—that is, original work new to the individual —but it is incompatible with research, the process of discovering things new to the scientific world. This is partly because of the lack of time necessary for research but mainly because research is too far removed from secondary school teaching.

Perhaps the most vital thing for any student is insight. There are two parts to insight: understanding a thing with respect to itself, and understanding a thing with respect to its ramifications; the first part must largely precede the second. For a prospective teacher, emphasis should be laid on firm understanding at the expense, if necessary, of coverage of ground. Proficiency of technics without understanding is, for a teacher, infinitely worse than no technics at all.

The secondary school teacher must have a broader base of knowledge than one who teaches in college. The teacher of mathematics, for example, must know the role of mathematics in economics, statistics and the sciences—things for which there is little time in the present graduate program. This need, along with required work in education and training in mathematical investigation, rather than the need for more courses in mathematics, makes a fifth year of study increasingly necessary. In considering the problem of training for investigation, it should be emphasized that while publication, the corollary of research, is probably the best way to "remain alive" in a subject, it does not insure it, and many who do not publish advance the frontiers of their own minds and maintain an unfailing interest in the subject. Training for investigation is vital for all students and here our present program is weakest. A master's thesis need be merely a piece of investigation, and the topic should be selected by the student. To aid in this selection, the student should be shown the beginnings of many interesting bypaths in elementary courses, and all the interesting questions raised in courses should not be answered. For the future Ph.D. many of these questions must be answered that he may build on these results; for the prospective teacher a broader, less

complete course is necessary in which basic methods are learned and many questions left unanswered.

The thesis should be written from the student's point of view, and its merit should be judged, not by its elegance or its interest to the professional scientist, but by the progress the student has made and the initiative and originality he has shown in writing it. A master's degree must imply that the holder is capable of improving his knowledge of the field.

It is the habit of those teaching in colleges to disparage secondary school teaching and to discourage their better students from entering it, at the same time complaining of the quality of instruction in high schools. If conditions are bad, they should be a challenge to good men to set them right. A high school teacher can seldom contribute to the advancement of scientific knowledge but he has a delicate and vital service to science to perform. College and high school teaching require different aptitudes. To give high school students a feeling for, and interest in, say, sound mathematics is difficult; later instruction is comparatively easy. Only by cooperation, which implies meeting on a basis of equality, can college and secondary school teachers work out a completely worthwhile program for teacher training.

In brief, the course of training for a prospective teacher in secondary schools should differ from that of a student going on to research in three fundamental ways: (1) it should be broader; (2) it should lay chief emphasis on thorough understanding; (3) it should give by the close of the first graduate year material for investigation as well as training in the field. The standards, though different, must be just as strict.—H. N. O.

Physics for Student Pilots

The ground school of the civilian pilot training program. D. L. Webster; *Air Facts* **3**, 16–23, 26–27 (1940). The ground instruction which is a part of the Civilian Pilot Training Program offers an unprecedented opportunity to accomplish the objectives that physics teachers consider most important. First we will review briefly the historical background of the program. As early as 1914, prospective army pilots were sent to ground schools; and in the last decade or more, with the growth of the air lines, there has been a corresponding growth in good ground school work in the civilian training centers for air line pilots. However, the great majority of civilian student pilots have not intended to go into professional flying, and for them the Army and Navy schools have been inaccessible, while the few schools that train for air line work have often been far away and expensive; consequently, they have usually learned to fly under the guidance of independent flight instructors working on a small scale. Flight instruction was expensive, even this way, and students were so few that it was a rare coincidence for any two of them to start instruction at the same time, and even rarer for them to keep together in their progress. Under such conditions, there were no classes to attend ground schools, and there was little, if any, coherent ground instruction. Another important factor in keeping the number of students small was the appalling frequency of accidents in private flying. In the magazine *Air Facts*, in 1938, there appeared the following paragraph:

> Anything that might throw further light on accident causes will be welcomed by all of us who are flying for a living and naturally believe we are doing it as safely as possible, and yet who have to admit that we have lost plenty of friends who were thinking the same. My own list of fairly close personal friends, pilots all, who have been fatally injured since I started to fly in 1925, is over thirty and still growing. It makes you stop and wonder, when you are not too busy explaining how safe the air is to prospective customers.

Air Facts has printed some significant comparisons between the "approved schools," which have official approval by the Bureau of Air Commerce, and the small schools or independent instructors who have not won such recognition. During 1937, the approved schools gave "nearly 20,000 hrs of dual instruction without a fatality, and their students flew *solo* approximately 40,000 hrs with only one fatality." But in the same year, in the other schools, even the instructors were killed once in 40,000 hrs, and the solo students had a fatal accident for every 4000 hrs. An automobile travels farther between fatalities than they did. Why this difference? With regard to the approved schools, *Air Facts* said, "Briefly, they (1) are thorough, (2) supervise all flying closely, (3) have good maintenance, (4) usually get the money in advance and do not worry about scaring some student away by showing him what is dangerous about flying." These four characteristics which distinguished the approved schools from the others in 1937 are indeed just those that have become widespread this year under the Civilian Pilot Training Program.

The first three characteristics—thoroughness, supervision of flight training and good maintenance of the airplanes—all relate to flight instruction, and the accomplishments of the C. P. T. program in the improvement of flight instruction have been most impressive. However, our concern here is with the part of pilot training in which physics teachers have the opportunity to help, namely, the ground instruction. In the contrast between the approved schools and the others, perhaps the most striking point was that the former had well-organized ground instruction, and the content of the ground courses was primarily physics. So, now that the vision of Langley and the Wright brothers is being fulfilled by the youth of America, we who are members of Langley's profession can play our part in its fulfillment.

From the viewpoint of safety, a primary function of the ground instruction in the approved schools is summed up in the fourth point made by *Air Facts*: showing the student the dangers of flying and how to avoid them. Yet there is far more to skilful flying than mere safety; there is efficiency, smoothness and accuracy. To be safe, but even more to acquire skill from any reasonable number of hours in the air, a pilot must have the scientific training of a good ground school, particularly the part known in this program as *theory of flight*. This need for science in flying contrasts rather strongly with the lack of such a need in driving a car; and it contrasts even more strongly, and very significantly for us, with the popular belief that

the chief need is quickness of reactions. The facts are almost exactly opposite to any such belief. Modern airplanes under normal flying conditions are inherently stable. Even if a gust of wind does make a ship jump, she will soon return to steady flight of her own accord, without anything being done to the controls. Indeed, one should never be hasty about doing anything with them, because too much quickness of reaction can make a rough ride out of one that a more deliberate pilot would take smoothly. In some training ships, this point is impressed on the student's mind continually by a sign on the instrument board consisting of the one word, RELAX! How about those accidents where the ships have been reported to have suddenly fallen out of control? How can a stable ship do that? The answer is, she is stable under normal flying conditions, but under other conditions may be anything but stable. These abnormal conditions all involve relative motion of the air at an angle with the wing chord so great that the air cannot flow in smooth streamlines, but must break into eddies. Such a condition can be created even in straight, level flight by closing the throttle too far and then maintaining level flight until the ship has lost considerable speed. But such loss of speed takes time; to prevent it requires, not quick reactions, but the knowledge that it can occur, and the foresight to use that knowledge when making any change in the controls, such as closing the throttle. Similar remarks apply to flight that is not straight and level. In turns of short radius, for example, the critical speed for instability is somewhat higher than in straight flight; and if the pilot makes the ship skid, like a car on a wet road, the difference in critical speeds is greater. In gusty winds, also, or near the ground, the precautions against instability are somewhat different. But in all such cases, the way to be safe is to know the possible causes of instability and to possess foresight in the use of that knowledge. This foresight may be difficult for a man to acquire unless he has already made a good start toward it long before the minimum age for certification as a student pilot. But the knowledge he needs can be given to any student with collegiate intelligence. Here is where the physicists come into the program; for the theory of flight, like most of what goes into pilot training, is good, straight physics.

Against other flying dangers, likewise, the prescription is almost always the same sort of compound of foresight and physics. For instance, a situation leading to many accidents is that in which the pilot allows himself to be caught by bad weather far from any really safe place to land. Even then he may improve his chances with the help of the theory of flight. If, for example, the only smooth ground in sight is on the slope of a hill, and he takes time to think, the theory of flight will tell him to land uphill, and he will know what to do if uphill is not also against the wind. But it would be much better to use still more foresight in planning the whole flight, and to do that with another branch of physics, *meteorology*, which also is taught in any good ground school.

Similar comments apply to another common danger, namely, when the pilot loses his way and cannot find his destination. In a car, one can usually find some town by keeping on a few miles, because most roads lead to towns. But, even if airports were only a few miles apart, an airplane flying in a random direction would usually miss the nearest ones, just as a gas molecule usually misses its neighbors. With airports far apart as they are now, the mean free path of an airplane in random flight would be much too long for its fuel supply. Again, the theory of flight might help; but what the pilot really needs to know here is what another science, navigation, can tell him: or, better yet, he should have used the rules of navigation earlier in planning the flight. So *navigation* is a third science taught in any good ground school.

A fourth subject, of importance coordinate with these, is the Civil Air Regulations, particularly the Air Traffic Rules; and along with this there must be some study of radio uses and terms. A subject of minor importance is *engines*, about which a pilot should know a little, even though the real responsibility here belongs to another man, with a different CAA certificate, the airplane mechanic. Aircraft structures, parachutes and instruments likewise are minor subjects. As a part of general culture, a pilot should know something of the history of aviation.

Last year the ground school of the C. P. T. Program covered the subjects listed in Table I with a distribution of emphasis approximately as indicated by the numbers of lecture hours prescribed by the CAA.

TABLE I. *Ground school program, 1939–1940.*

SUBJECT	HOURS
Theory of flight and aircraft	15
Meteorology	15
Navigation	15
Civil Air Regulations	12
Engines	5
Instruments	5
Radio uses and terms	2
Parachutes	1
History of aviation	2

These numbers were minimum requirements, and the individual teacher had freedom to increase any of them. At Stanford University they were increased for theory of flight and meteorology, making the total course 80 hours, rather than 72, to fit into the calendar on the quarter system with 4 lectures per week for 2 quarters. Since the class included students from all departments, from engineering to English, a medium amount of mathematical background was assumed, about as in first-year physics for students majoring in the non-engineering sciences. At that, even the engineers had enough new things to think about to earn all of the 8 quarter-units of credit toward graduation.

In this program we are teaching people something they will use for a practical purpose, and any such teaching affords a definite sense of accomplishment. But it is more than that. These CAA students, especially in theory of flight, meteorology and navigation, know that they are actually preparing to bet their lives on their knowledge! If these seem to be strong words, recall that only 3 years ago a fatal accident occurred for every 4000 hrs of solo flying; and enough hours were flown for rough statistical analysis. This year, in the C. P. T. program, with well-planned flight instruction and good ground schools, there has been only one fatality in approximately 150,000 hrs of solo flying.

Good flying is not only safe, but efficient and smooth. Skill in flying may be acquired by long practice and careful observation of the results of whatever one does. But 35 hrs in the air is anything but long, so each hour must be made to count for many. This can be done only by first knowing what to observe, and this means knowing the subjects taught in the ground school. The students realize this, and seeing, furthermore, that foresight as well as science is needed in flying and in flight planning, they get to work and plan their flights in the ground school with an unusual degree of enthusiasm for study and clear thinking. To physics teachers, with their interest in the use of physics as training in clear thinking, this is a grand opportunity! Evidently the opportunity is at its best in the theory of flight. To understand what one is dealing with in using wings, he must know what makes them lift, and how they do it; Newton's third law, the laws of forces on bodies moving in curves, as applied to the air in its streamlines, and the Bernouilli theorem are important here. Other effects of motion in curves, with the same laws, are prominent in a turning airplane, because of its high speed. No force is so apparently real and important during turns as centrifugal force. The pilot must understand that when he feels heavy, so does the ship; that if he loads the seat with just twice its normal load, the ship loads her wings in exactly the same ratio. Another bit of elementary physics that comes in here is the theory of bodies sliding on inclined planes, with forces like those on an airplane in a glide or climb. Linear acceleration comes under discussion, as applied to an airplane getting up speed on the ground; with a row of trees across the end of the airport, acceleration becomes of vital importance.

The practical value of a knowledge of physical laws in learning to fly is evident to anyone who already knows the laws. Its value is also confirmed by experience, as I can testify from having tried the experiment twice: learning to fly in 1918, when safety was more of a problem than it is now; getting back into the air in 1936 after 17 years on the ground, and finding considerable changes in the design of ships and their ways of telling one what they are doing. Both times, physics told me just what to look for in the air.

Since most pilots who acquired certificates prior to last autumn had learned flying in small schools or from independent instructors, their attitude toward physics was much like that of many older engineers toward mathematics. All who have taught physics to engineering students can remember the boy whose "Uncle is an engineer making $15,000 a year, and I asked him about it, and he said he never saw the inside of a calculus book and didn't think anybody that's good would need it; so why should I have to learn that stuff?" Most likely, Uncle graduated from the School of Hard Knocks, where also most of the flight instructors of today had their training. As a CAA inspector said to me about some of the points covered in the theory of flight, "It took me thousands of hours in the air to learn those things." Plenty of hard knocks, there must have been, in those thousands of hours; and like the old instructor writing in *Air Facts*, he could remember many friends whom those hard knocks had carried off. Graduates of the School of Hard Knocks are always distrustful of anything called "theory." In truth, no short course in the theory of flight can ever make pilots as safe with only 35 hrs in the air as are these men with their thousands of hours. But we can afford many hours in the classroom to save even a few of such hazardous hours in the air, between the first solo flight and the safety those oldtimers have now. However, the ground instructor must be prepared for the different viewpoint of the flight instructor, and for its effect on the students. If this is sometimes disconcerting, he should remember that its origin is in circumstances chiefly in the past, and then inevitable. Moreover, there really is something, intangible but important, that the older pilots got and the present students are missing; the new, safe instruction does not provide the same need for facing danger and maintaining self-control, or, later, the inner rewards of victory.

Turning to other parts of the ground school course, we find applications of still other branches of physics. In meteorology, almost every motion of the air is an illustration of the adiabatic gas law; the relation of winds to isobars is good elementary dynamics; and radiation laws are illustrated in the heating and cooling of the air, and the formation of some kinds of fogs. Thermodynamics figures most prominently here, since the atmosphere as a whole is a gigantic heat engine. Almost every branch of physics is represented in modern meteorology; and the laboratory is all outdoors, with some experiment always going on. Even with all the aid the weather services give, through hourly radio reports from points on the airways and radio forecasts every 6 hours, the private pilot must still be able to interpret and extrapolate, from the weather map and from all local indications, the type of weather he is likely to meet. To the nonobserving person a cloud is just a cloud; to the flyer it may mean, "Take off" or "Stay on the ground." Any science, such as this, that teaches the student to be aware of what goes on around him, ought to be good training for any field of activity. For aviation it is vitally so. In few other fields of physics is a little observation and a little knowledge so richly rewarded in understanding as in meteorology. To understand nature is a source of satisfaction and certainly is one aim of teaching physics. Here is a place where anyone can begin with only elementary physics.

Other parts of the ground school course, notably those dealing with engines and instruments, afford good applications of physics. Navigation provides a vast field for developing the powers of observation and judgment, and offers good training in elementary mathematics. However, enough has been said about theory of flight and meteorology to illustrate the kinds of subjects in the CAA ground school course, and how they are motivated in the minds of the students. This material, and this motivation, are indeed the answer to physics teachers' dreams.